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(54) **SPARK PLUG**

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H01T 13/41 (2006.01)
F02P 11/00 (2006.01)

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CPC ***H01T 13/05*** (2013.01); ***F02P 11/00*** (2013.01); ***H01T 13/41*** (2013.01)

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CPC H01T 13/36; H01T 13/42; H01T 13/05; H01T 13/41; H01T 13/462; H01T 13/467; H01T 13/54; H01T 19/00; F02P 11/00
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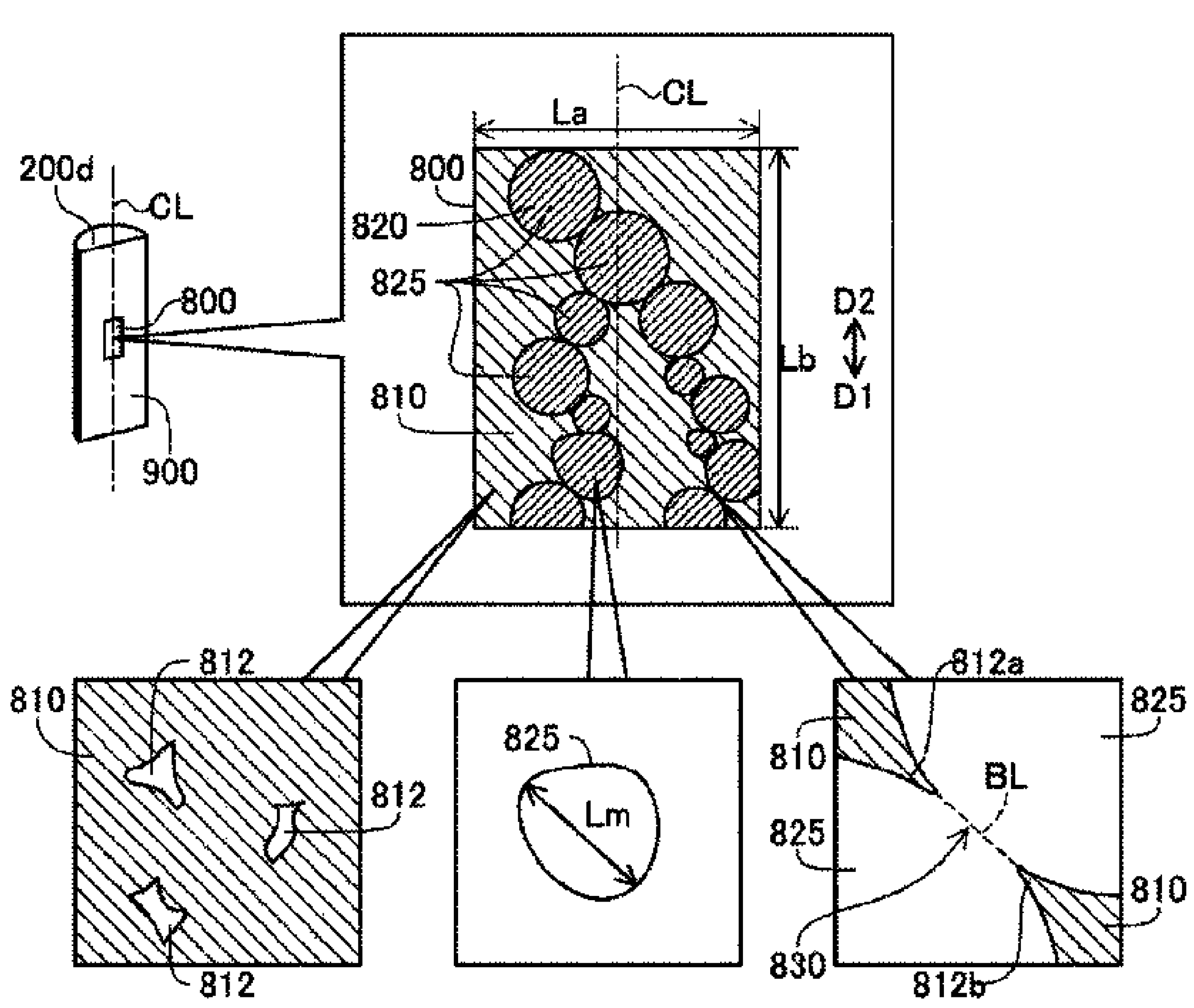
(57) **ABSTRACT**

A connection portion connecting a center electrode and a terminal metal fixture together in a through hole of the insulator includes a resistor and a magnetic substance structure including a magnetic substance and a conductor and being disposed on a leading end side or a rear end side of the resistor while being positioned away from the resistor. The connection portion further includes a first conductive sealing portion, a second conductive sealing portion and a third conductive sealing portion. The first conductive sealing portion is disposed on a leading end side of a first member and is in contact therewith. The second conductive sealing portion is disposed between the first member and a second
(Continued)



member and is in contact with the first and second members. The third conductive sealing portion is disposed on a rear end side of the second member and is in contact therewith.

12 Claims, 5 Drawing Sheets

(58) **Field of Classification Search**
USPC 313/118–147
See application file for complete search history.

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FIG.1

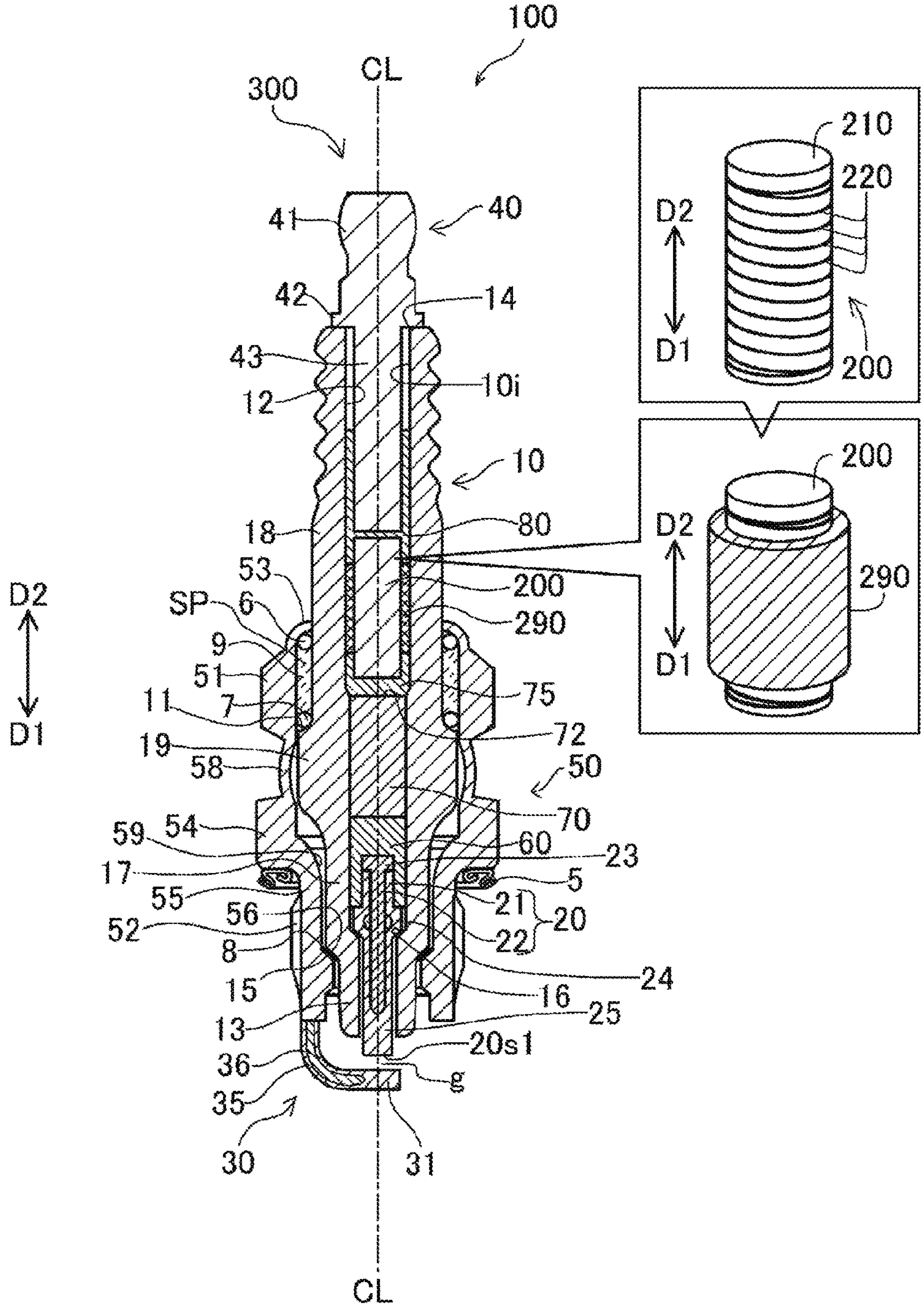
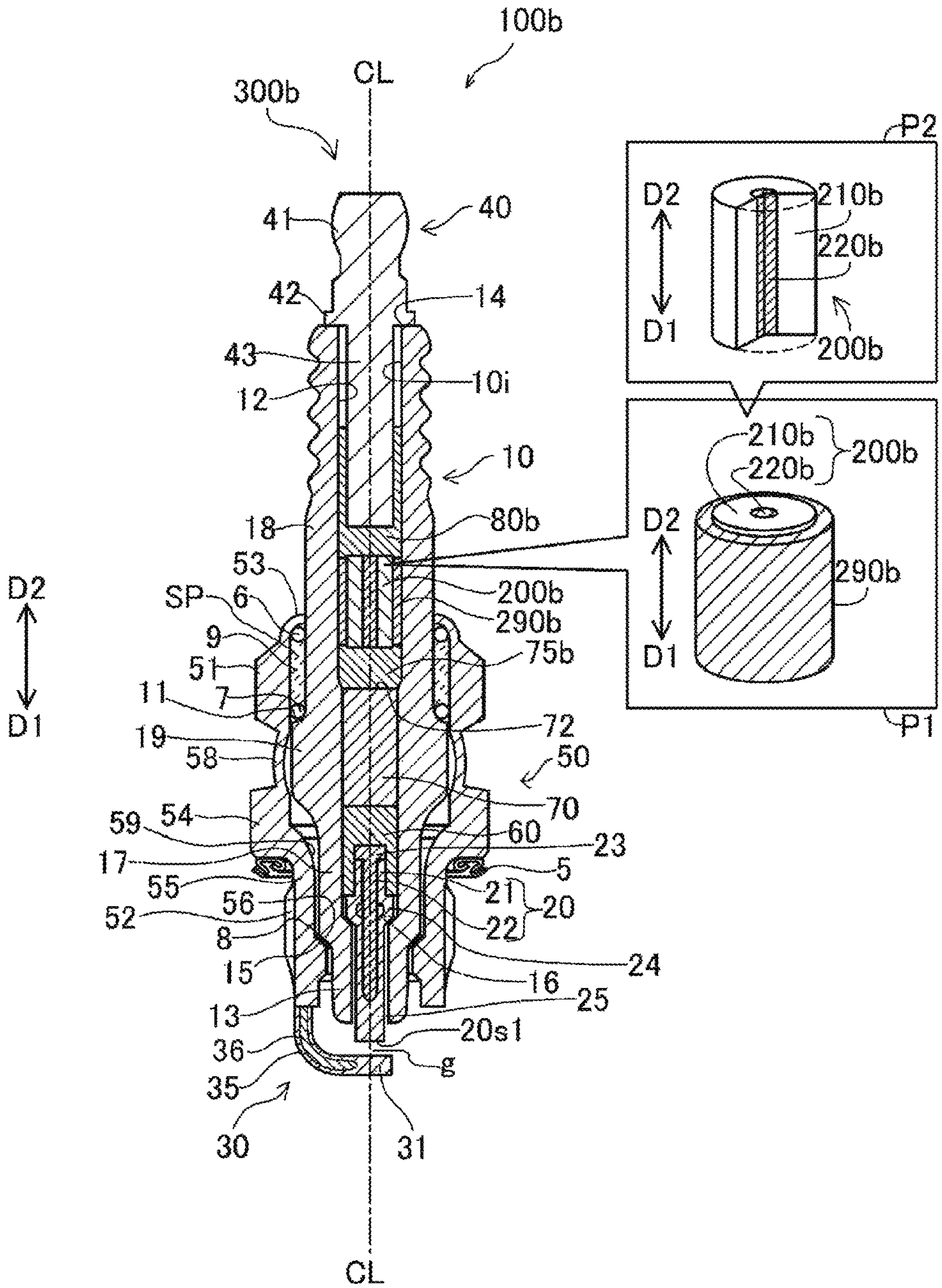

100
CL
300
210
220
40
41
42
14
D2
D1
200
43
10i
12
10
200
18
80
D2
53
200
290
SP
6
290
9
D1
51
75
11
7
D1
72
19
50
58
70
54
59
60
23
17
5
55
21
20
56
52
22
8
24
15
16
13
25
20s1
36
g
35
30
31
CL

FIG.2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300b
CL
40
41
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14
43
12
10i
10
18
80b
53
SP
6
200b
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51
75b
11
7
72
19
58
50
70
54
59
60
23
17
5
55
21
20
56
52
22
8
24
15
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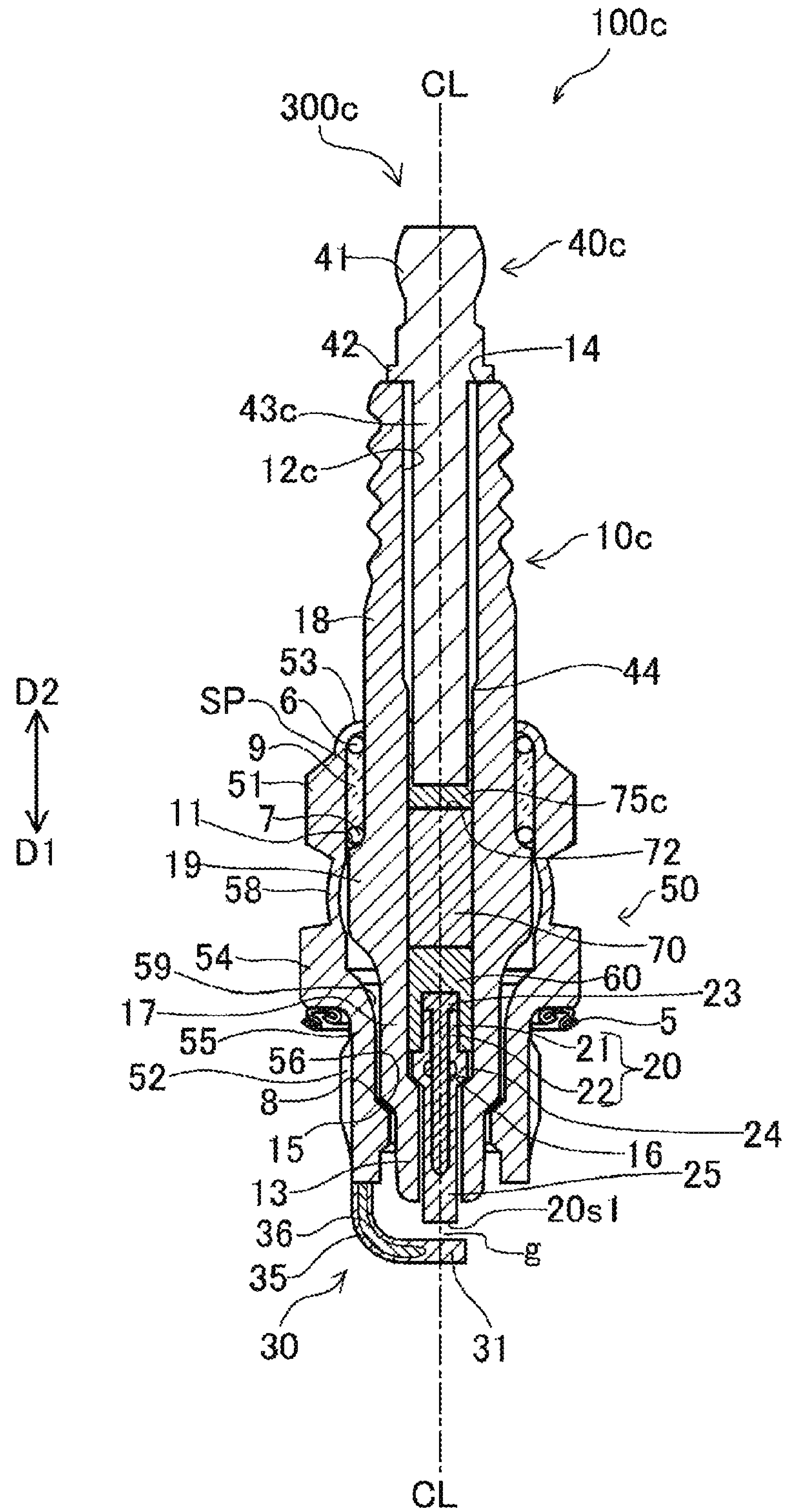
D2
D1
P2
210b
220b
P1

FIG.3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CL
300c
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40c
42
14
43c
12c
10c
18
53
44
D2
SP
6
9
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75c
11
7
D1
72
19
58
50
70
54
59
60
23
17
5
55
21
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36
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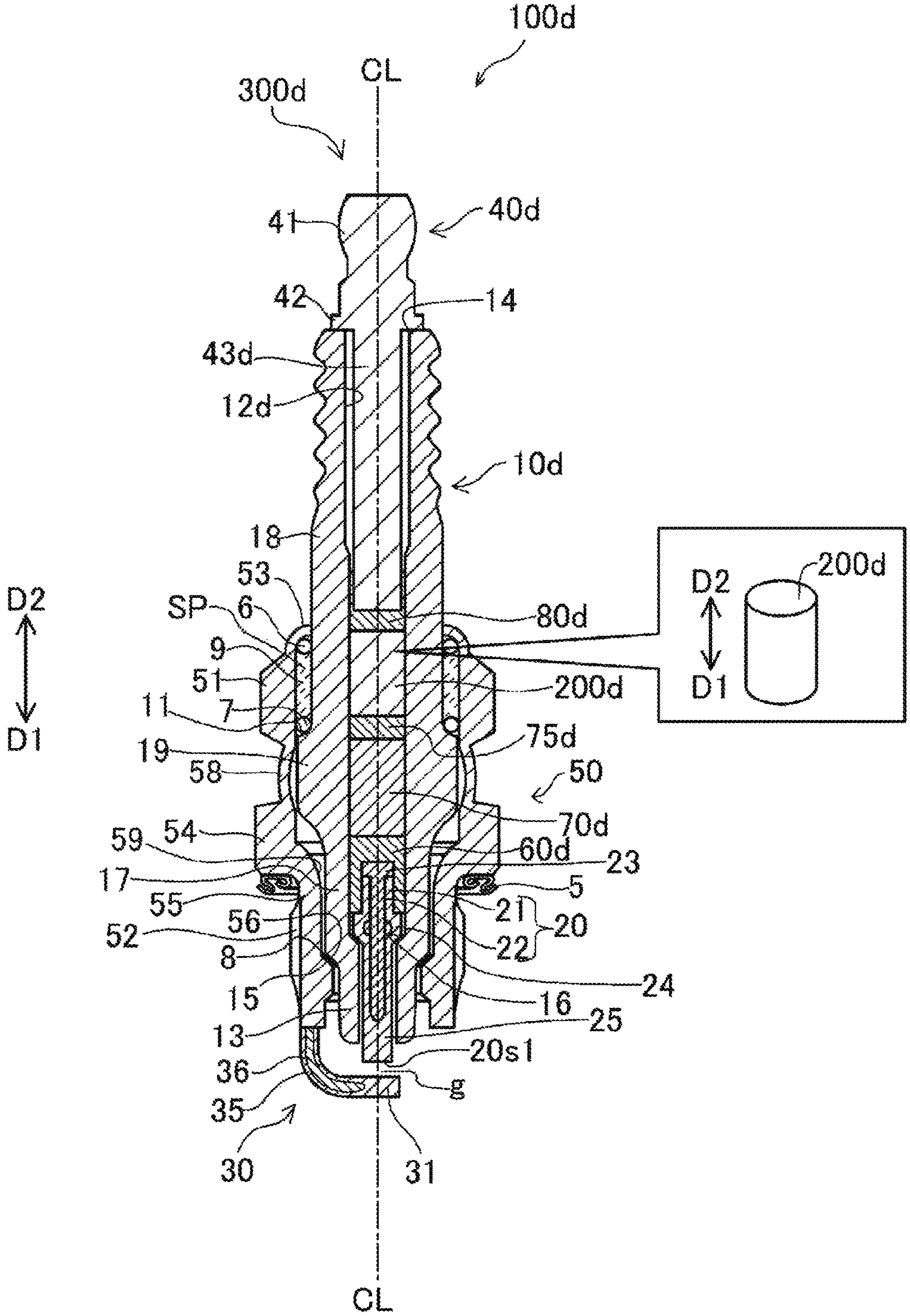
35
30
31
CL

FIG.4



100d
CL
300d
41
40d
42
14
43d
12d
10d
18
53
80d
200d
D2
D1
SP
6
9
51
11
7
75d
19
58
50
54
70d
59
60d
23
17
5
55
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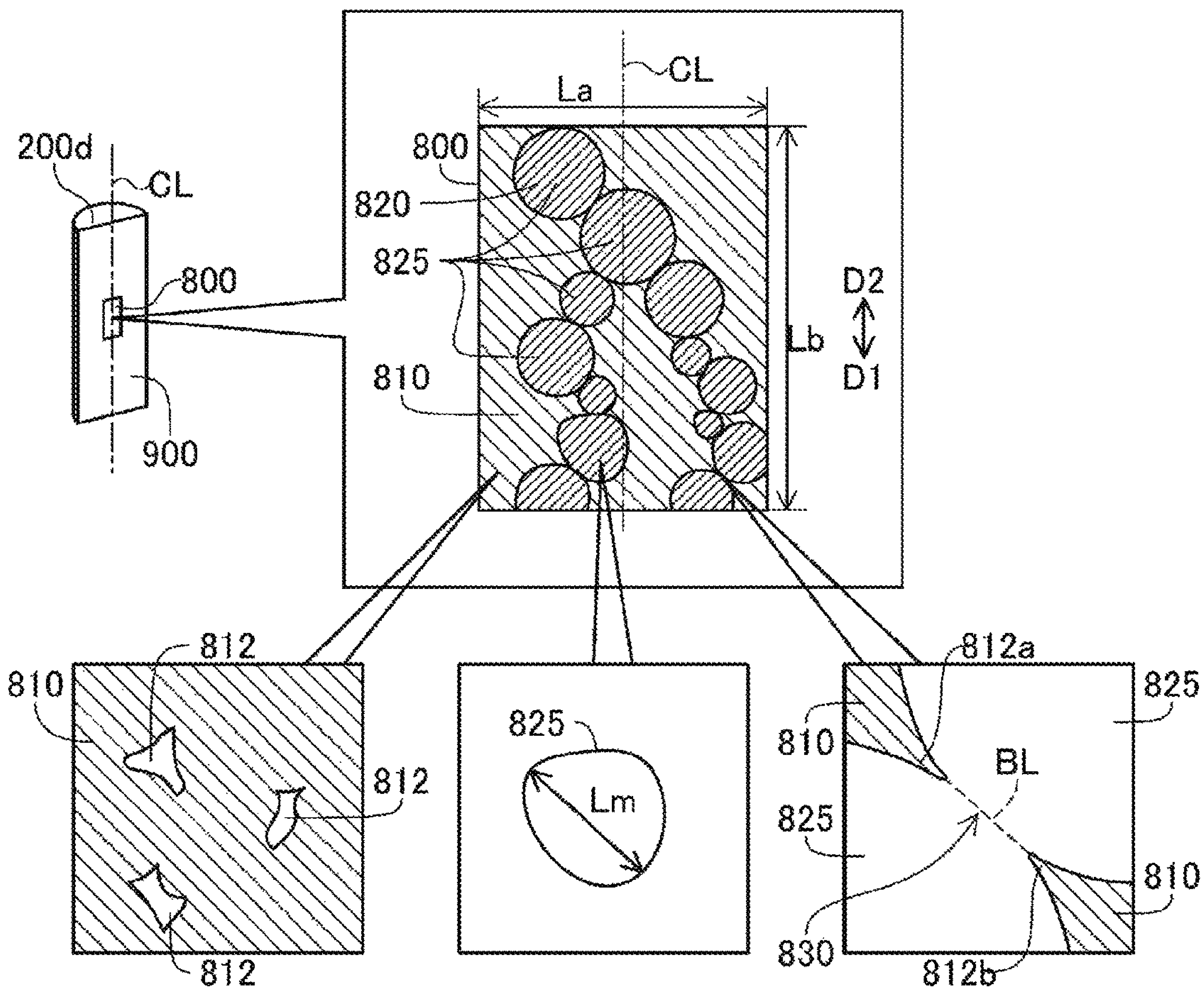
g
35
30
31

FIG.5


200d
CL
800
900
La
CL
800
820
825
810
Lb
D2
D1
810
812
812
812
825
Lm
812a
825
810
BL
825
810
830
812b

SPARK PLUG

RELATED APPLICATIONS

This application is a National Stage of International Application No. PCT/JP2014/084393 filed Dec. 25, 2014, which claims the benefit of Japanese Patent Application No. 2013-266957, filed Dec. 23, 2013.

FIELD OF THE INVENTION

The present invention relates to a spark plug.

BACKGROUND OF THE INVENTION

Conventionally, a spark plug has been used in an internal combustion engine. Technology, by which a resistor is provided in a through hole of an insulator so as to suppress occurrence of electromagnetic noise induced by ignition, has been proposed. Technology, by which a magnetic substance is provided in the through hole of the insulator, has also been proposed.

The fact is that enough study regarding the suppression of electromagnetic noise by both the resistor and the magnetic substance has not been made.

This disclosure discloses technology by which the occurrence of electromagnetic noise can be suppressed by a resistor and a magnetic substance.

SUMMARY OF THE INVENTION

This disclosure discloses the following application examples and the like.

APPLICATION EXAMPLE 1

In accordance with a first aspect of the present invention, there is provided a spark plug comprising:

an insulator having a through hole extending in a direction of an axial line;

a center electrode, at least a part of which is inserted into a leading end side of the through hole;

a terminal metal fixture, at least a part of which is inserted into a rear end side of the through hole; and

a connection portion connecting the center electrode and the terminal metal fixture together in the through hole,

wherein the connection portion includes:

a resistor; and

a magnetic substance structure including a magnetic substance and a conductor and being disposed on a leading end side or a rear end side of the resistor while being positioned away from the resistor,

wherein, among the resistor and the magnetic substance structure, when a member disposed on a leading end side is defined as a first member and a member disposed on a rear end side is defined as a second member, the connection portion further includes:

a first conductive sealing portion that is disposed on a leading end side of the first member and is in contact with the first member;

a second conductive sealing portion that is disposed between the first member and the second member and is in contact with the first member and the second member; and

a third conductive sealing portion that is disposed on a rear end side of the second member and is in contact with the second member,

wherein the magnetic substance structure contains:

(1) a conductive substance as the conductor;

(2) an iron-containing oxide as the magnetic substance; and

(3) a ceramic containing at least one of silicon (Si), boron (B), and phosphorous (P), and

wherein, in a cross-section of the magnetic substance structure including the axial line, when a target region is defined as a rectangular region having the axial line as a center line, a side of 1.5 mm in a direction perpendicular to the axial line, and a side of 2.0 mm in the direction of the axial line,

a region of the conductive substance includes a plurality of grain-shaped regions in the target region,

a proportion of a number of grain-shaped regions having a maximum grain size of 200 μm or greater among the plurality of grain-shaped regions is 40% or more, and

a proportion of an area of the region of the conductive substance is 35% or greater and 65% or less in the target region.

In this configuration, it is possible to suppress occurrence of an electrical contact failure at both ends of the resistor and an electrical contact failure at both ends of the magnetic substance structure by using the first, the second, and the third conductive sealing portions. Accordingly, it is possible to appropriately suppress electromagnetic noise by using both the resistor and the magnetic substance structure. Further, it is possible to appropriately suppress noise by adopting a specific configuration of the magnetic substance structure.

APPLICATION EXAMPLE 2

In accordance with a second aspect of the present invention, there is provided a spark plug as described above, wherein an electrical resistance between a leading end and a rear end of the magnetic substance structure is less than or equal to 3 kΩ.

In this configuration, it is possible to suppress heat generation of the magnetic substance structure. Accordingly, it is possible to suppress the occurrence of a failure (for example, alteration of the magnetic substance) induced by heat generation of the magnetic substance structure.

APPLICATION EXAMPLE 3

In accordance with a third aspect of the present invention, there is provided a spark plug as described above, wherein the electrical resistance between the leading end and the rear end of the magnetic substance structure is less than or equal to 1 kΩ.

In this configuration, it is possible to further suppress heat generation of the magnetic substance structure. Accordingly, it is possible to further suppress the occurrence of a failure (for example, alteration of the magnetic substance) induced by heat generation of the magnetic substance structure.

APPLICATION EXAMPLE 4

In accordance with a fourth aspect of the present invention, there is provided a spark plug as described above, wherein the conductor includes a conductive portion penetrating through the magnetic substance in the direction of the axial line.

In this configuration, it is possible to appropriately suppress electromagnetic noise while improving durability.

APPLICATION EXAMPLE 5

In accordance with a fifth aspect of the present invention, there is provided a spark plug as described above, wherein the magnetic substance structure is disposed on the rear end side of the resistor.

In this configuration, it is possible to appropriately suppress electromagnetic noise.

APPLICATION EXAMPLE 6

In accordance with a sixth aspect of the present invention, there is provided a spark plug as described above, wherein the connection portion further includes a covering portion that covers at least a part of an outer surface of the magnetic substance structure while being interposed between the magnetic substance structure and the insulator.

In this configuration, it is possible to suppress direct contact between the insulator and the magnetic substance structure.

APPLICATION EXAMPLE 7

In accordance with a seventh aspect of the present invention, there is provided a spark plug as described above, wherein the magnetic substance is made of a ferromagnetic material containing an iron oxide.

In this configuration, it is possible to appropriately suppress electromagnetic noise.

APPLICATION EXAMPLE 8

In accordance with an eighth aspect of the present invention, there is provided a spark plug as described above, wherein the ferromagnetic material is a spinel type ferrite.

In this configuration, it is possible to easily suppress electromagnetic noise.

APPLICATION EXAMPLE 9

In accordance with a ninth aspect of the present invention, there is provided a spark plug as described above, wherein the magnetic substance is a NiZn ferrite or a MnZn ferrite.

In this configuration, it is possible to appropriately suppress electromagnetic noise.

APPLICATION EXAMPLE 10

In accordance with a tenth aspect of the present invention, there is provided a spark plug as described above, wherein the conductive substance contains a perovskite type oxide which is represented by general formula ABO_3 and an A site in the general formula is at least one of La, Nd, Pr, Yb, and Y.

In this configuration, it is possible to further appropriately suppress electromagnetic noise.

APPLICATION EXAMPLE 11

In accordance with an eleventh aspect of the present invention, there is provided a spark plug as described above, wherein the conductive substance contains at least one metal of Ag, Cu, Ni, Sn, Fe, and Cr.

In this configuration, it is possible to further appropriately suppress electromagnetic noise.

APPLICATION EXAMPLE 12

In accordance with a twelfth aspect of the present invention, there is provided a spark plug as described above, wherein, in the target region in the cross-section of the magnetic substance structure, a porosity of a remainder of the target region other than the region of the conductive substance is less than or equal to 5%.

In this configuration, it is possible to improve durability of the magnetic substance structure.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a cross-sectional view of a spark plug **100** in a first embodiment.

FIG. **2** is a cross-sectional view of a spark plug **100*b*** in a second embodiment.

FIG. **3** is a cross-sectional view of a spark plug **100*c*** in a reference example.

FIG. **4** is a cross-sectional view of a spark plug **100*d*** in a third embodiment.

FIG. **5** shows views illustrating a magnetic substance structure **200*d***.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. First Embodiment

A-1. Configuration of Spark Plug

FIG. **1** is a cross-sectional view of a spark plug **100** in a first embodiment. An illustrated line CL is a center axis of the spark plug **100**. The illustrated cross-section is a cross-section including the center axis CL. Hereinafter, the center axis CL may be referred to as an "axial line CL", and a direction parallel with the center axis CL may be referred to as a "direction of the axial line CL", or simply as an "axial direction". A radial direction of a circle centered around the center axis CL may be simply referred to as a "radial direction", and a circumferential direction of the circle centered around the center axis CL may be referred to as a "circumferential direction". In FIG. **1**, among the directions parallel with the center axis CL, a downward direction may be referred to as a leading end direction D**1**, and an upward direction may be referred to as a rear end direction D**2**. The leading end direction D**1** is a direction running from a terminal metal fixture **40** (to be described later) toward electrodes **20** and **30**. In FIG. **1**, the leading end direction D**1** side is referred to as the leading end side of the spark plug **100**, and the rear end direction D**2** side is referred to as the rear end side of the spark plug **100**.

The spark plug **100** includes an insulator **10** (may be referred to as a "ceramic insulator **10**"); the center electrode **20**; the ground electrode **30**; the terminal metal fixture **40**; a metal shell **50**; a first conductive sealing portion **60**; a resistor **70**; a second conductive sealing portion **75**; a magnetic substance structure **200**; a covering portion **290**; a third conductive sealing portion **80**; a leading end side packing **8**; talc **9**; a first rear end-side packing **6**; and a second rear end-side packing **7**.

The insulator **10** is a substantially tubular member which extends along the center axis CL and has a through hole **12** (may be referred to as an "axial hole **12**") penetrating through the insulator **10**. The insulator **10** is made of alumina by firing (another insulating material may also be adopted). The insulator **10** includes a leg portion **13**; a first reduced outer diameter portion **15**; a leading end side trunk portion **17**; a flanged portion **19**; a second reduced outer diameter portion **11**; and a rear end-side trunk portion **18**, which line up sequentially from the leading end side toward the rear end side.

The flanged portion **19** is a portion of the insulator **10** which has the maximum outer diameter. An outer diameter of the first reduced outer diameter portion **15** positioned closer to the leading end side than the flanged portion **19** is gradually reduced from the rear end side toward the leading end side. A reduced inner diameter portion **16** is formed in the vicinity of the first reduced outer diameter portion **15** of the insulator **10** (the leading end side trunk portion **17** in the example illustrated in FIG. **1**), and an inner diameter of the reduced inner diameter portion **16** is gradually reduced from the rear end side toward the leading end side. An outer diameter of the second reduced outer diameter portion **11** positioned closer to the rear end side than the flanged portion **19** is gradually reduced from the leading end side toward the rear end side.

The center electrode **20** is inserted into a leading end side of the through hole **12** of the insulator **10**. The center electrode **20** is a bar-shaped member which extends along the center axis CL. The center electrode **20** includes an electrode base member **21** and a core member **22** embedded in the electrode base member **21**. For example, the electrode base member **21** is made of Inconel ("INCONEL" is registered trademark) that is an alloy containing nickel as a main component. The core member **22** is made of a material (for example, an alloy containing copper) having a coefficient of thermal conductivity greater than that of the electrode base member **21**.

With focus given to an outer shape of the center electrode **20**, the center electrode **20** includes a leg portion **25** formed at the end of the center electrode **20** on the leading end direction D**1** side; a flanged portion **24** provided on the rear end side of the leg portion **25**; and a head portion **23** provided on the rear end side of the flanged portion **24**. The head portion **23** and the flanged portion **24** are disposed in the through hole **12**, and the surface of the flanged portion **24** on the leading end direction D**1** side is supported by the reduced inner diameter portion **16** of the insulator **10**. A leading end side portion of the leg portion **25** is positioned on the leading end side of the insulator **10**, and is exposed to the outside from the through hole **12**.

The terminal metal fixture **40** is inserted into the rear end side of the through hole **12** of the insulator **10**. The terminal metal fixture **40** is made of a conductive material (metal such as low-carbon steel). An anti-corrosion metal layer may be formed on the surface of the terminal metal fixture **40**. For example, a Ni layer may be formed by plating. The terminal metal fixture **40** includes a flange portion **42**; a cap installation portion **41** that is formed to a portion of the terminal metal fixture **40** positioned closer to the rear end side than the flanged portion **42**; and a leg portion **43** that is formed to a portion of the terminal metal fixture **40** positioned closer to the leading end side than the flanged portion **42**. The cap installation portion **41** is positioned on the rear end side of the insulator **10**, and is exposed to the outside from the through hole **12**. The leg portion **43** is inserted into the through hole **12** of the insulator **10**.

The resistor **70** suppressing electrical noise is disposed in the through hole **12** of the insulator **10** while being interposed between the terminal metal fixture **40** and the center electrode **20**. The resistor **70** is made of a composite containing glass particles (for example, B_2O_3—SiO_2 based glass) as a main component, and containing ceramic particles (for example, ZrO_2) and a conductive material (for example, carbon particles) in addition to the glass.

The magnetic substance structure **200** suppressing electrical noise is disposed in the through hole **12** of the insulator **10** while being interposed between the resistor **70** and the terminal metal fixture **40**. On the right side of FIG. **1**, a perspective view of the magnetic substance structure **200** covered with the covering portion **290** and a perspective view of the magnetic substance structure **200** from which the covering portion **290** is removed are illustrated. The magnetic substance structure **200** includes a magnetic substance **210** and a conductor **220**.

The magnetic substance **210** is a member that has a shape of a substantially circular column having the center axis CL as the center. For example, the magnetic substance **210** is made of a ferromagnetic material containing iron oxide. Spinel-type ferrite, hexagonal ferrite, and the like may be adopted as the ferromagnetic material containing iron oxide. NiZn (nickel-zinc) ferrite, MnZn (manganese-zinc) ferrite, CuZn (copper-zinc) ferrite, and the like may be adopted as the spinel-type ferrite.

The conductor **220** is a spiral coil surrounding the outer circumference of the magnetic substance **210**. The conductor **220** is made of a metal wire, for example, an alloy wire material containing nickel and chromium as main components. The conductor **220** is wrapped around the magnetic substance **210**, and extends from the vicinity of the end of the magnetic substance **210** on the leading end direction D**1** side to the vicinity of the end of the magnetic substance **210** on the rear end direction D2 side.

The first conductive sealing portion **60** is disposed between the resistor **70** and the center electrode **20** in the through hole **12** while being in contact with the resistor **70** and the center electrode **20**. The second conductive sealing portion **75** is disposed between the resistor **70** and the magnetic substance structure **200** while being in contact with the resistor **70** and the magnetic substance structure **200**. The third conductive sealing portion **80** is disposed between the magnetic substance structure **200** and the terminal metal fixture **40** while being in contact with the magnetic substance structure **200** and the terminal metal fixture **40**. The sealing portions **60**, **75** and **80** contain similar glass particles as those of the resistor **70** and metal particles (Cu, Fe, and the like).

The center electrode **20** is electrically connected to the terminal metal fixture **40** via the resistor **70**, the magnetic substance structure **200**, and the sealing portions **60**, **75**, and **80**. That is, the first conductive sealing portion **60**, the resistor **70**, the second conductive sealing portion **75**, the magnetic substance structure **200**, and the third conductive sealing portion **80** form a conductive path through which the center electrode **20** is electrically connected to the terminal metal fixture **40**. It is possible to stabilize the contact resistance between the members **20**, **60**, **70**, **75**, **200**, **80** and **40** stacked on top of each other, and to stabilize the electrical resistance value between the center electrode **20** and the terminal metal fixture **40** by using the conductive sealing portions **60**, **75**, and **80**. Hereinafter, all of a plurality of members **60**, **70**, **75**, **200**, **290** and **80**, which are disposed in the through hole **12** and connect the center electrode **20** and the terminal metal fixture **40** together, may be referred to as a "connection portion **300**".

In FIG. **1**, a position **72** (may be referred to as a "rear end position **72**") of the end of the resistor **70** on the rear end direction D2 side is illustrated. With respect to the through hole **12** of the insulator **10**, an inner diameter of a portion disposed on the rear end direction D2 side of the rear end position **72** is slightly larger than an inner diameter of a portion disposed on the leading end direction D**1** side of the rear end position **72** (particularly, a portion accommodating the first conductive sealing portion **60** and the resistor **70**). However, both inner diameters may be the same.

The outer circumferential surface of the magnetic substance structure **200** is covered with the covering portion **290**. The covering portion **290** is a tubular member covering the outer circumference of the magnetic substance structure **200**. The covering portion **290** is interposed between an inner circumferential surface **10***i* of the insulator **10** and an outer circumferential surface of the magnetic substance structure **200**. The covering portion **290** is made of glass (for example, borosilicate glass). During the operation of an internal combustion engine (not illustrated) equipped with the spark plug **100**, vibration is transmitted from the internal combustion engine to the spark plug **100**. The vibration may cause a positional offset between the insulator **10** and the magnetic substance structure **200**. However, in the spark plug **100** according to the first embodiment, the covering portion **290** disposed between the insulator **10** and the magnetic substance structure **200** absorbs vibration, and thus the positional offset between the insulator **10** and the magnetic substance structure **200** can be suppressed.

The metal shell **50** is a substantially tubular member which extends along the center axis CL and has a through hole **59** penetrating through the metal shell **50**. The metal shell **50** is made of low-carbon steel (another conductive material (for example, a metal material) may also be adopted). An anti-corrosion metal layer may be formed on the surface of the metal shell **50**. For example, a Ni layer may be formed by plating. The insulator **10** is inserted into the through hole **59** of the metal shell **50**, and the metal shell **50** is fixed to the outer circumference of the insulator **10**. The leading end of the insulator **10** (in the embodiment, a leading end side portion of the leg portion **13**) is exposed to the outside at the leading end side of the through hole **59** of the metal shell **50**. The rear end (in the embodiment, a rear end-side portion of the rear end-side trunk portion **18**) of the insulator **10** is exposed to the outside on the rear end side of the through hole **59** of the metal shell **50**.

The metal shell **50** includes a trunk portion **55**; a seat portion **54**; a deformed portion **58**; a tool engagement portion **51**; and a crimped portion **53** which line up sequentially from the leading end side toward the rear end side. The seat portion **54** is a flange-like portion. The trunk portion **55** positioned on the leading end direction D**1** side of the seat portion **54** has an outer diameter smaller than that of the seat portion **54**. A screw portion **52** is formed in the outer circumferential surface of the trunk portion **55**, and is screwed into an attachment hole of an internal combustion engine (for example, a gasoline engine). An annular gasket **5** is fitted into the gap between the seat portion **54** and the screw portion **52**, and is formed by folding a metal plate.

The metal shell **50** includes a reduced inner diameter portion **56** disposed closer to the leading end direction D**1** side than the deformed portion **58**. The inner diameter of the reduced inner diameter portion **56** is gradually reduced from the rear end side toward the leading end side. The leading end side packing **8** is interposed between the reduced inner diameter portion **56** of the metal shell **50** and the first reduced outer diameter portion **15** of the insulator **10**. The leading end side packing **8** is a steel O-ring (another material (for example, metal material such as copper) may also be adopted).

The deformed portion **58** of the metal shell **50** is deformed in such a way that a center portion of the deformed portion **58** protrudes outward (a direction away from the center axis CL) in the radial direction. The tool engagement portion **51** is provided on the rear end side of the deformed portion **58**. The tool engagement portion **51** is formed to have a shape (for example, a shape of a hexagonal column) so that a spark plug wrench can be engaged with the tool engagement portion **51**. The crimped portion **53** is provided on the rear end side of the tool engagement portion **51**, and has a thickness thinner than that of the tool engagement portion **51**. The crimped portion **53** is disposed closer to the rear end side than the second reduced outer diameter portion **11** of the insulator **10**, and forms the rear end (that is, the end on the rear end direction D**2** side) of the metal shell **50**. The crimped portion **53** is bent inward in the radial direction.

An annular space SP is formed between the inner circumferential surface of the metal shell **50** and the outer circumferential surface of the insulator **10**, and is positioned on the rear end side of the metal shell **50**. In the embodiment, the space SP is a space surrounded by the crimped portion **53** and the tool engagement portion **51** of the metal shell **50**, and the second reduced outer diameter portion **11** and the rear end-side trunk portion **18** of the insulator **10**. The first rear end-side packing **6** is disposed in the space SP on the rear end side, and the second rear end-side packing **7** is disposed in the space SP on the leading end side. In the embodiment, the rear end-side packings **6** and **7** are steel C-rings (another material may also be adopted). The gap between the rear end-side packings **6** and **7** in the space SP is filled with a powder of talc **9**.

When the spark plug **100** is manufactured, the crimped portion **53** is crimped in such a way as to be bent inward. The crimped portion **53** is pressed toward the leading end direction D**1** side. Accordingly, the deformed portion **58** is deformed, and the insulator **10** is pressed toward the leading end side via the packings **6** and **7** and the talc **9** in the metal shell **50**. The leading end side packing **8** is pressed between the first reduced outer diameter portion **15** and the reduced inner diameter portion **56**, and the gap between the metal shell **50** and the insulator **10** is sealed. Accordingly, the leaking of gas in a combustion chamber of an internal combustion engine to the outside through the gap between the metal shell **50** and the insulator **10** is suppressed. Further, the metal shell **50** is fixed to the insulator **10**.

The ground electrode **30** is joined to the leading end (that is, the end on the leading end direction D**1** side) of the metal shell **50**. In the embodiment, the ground electrode **30** is a bar-shaped electrode. The ground electrode **30** extends toward the leading end direction D**1** from the metal shell **50**, is bent toward the center axis CL, and then reaches a leading end portion **31**. A gap g is formed between the leading end portion **31** and a leading end surface **20***s***1** (a surface of **20***s***1** on the leading end direction D**1** side) of the center electrode **20**. The ground electrode **30** is electrically conductively joined to the metal shell **50** (for example, by laser welding). The ground electrode **30** includes a base member **35** forming the surface of the ground electrode **30**, and a core portion **36** embedded in the base member **35**. For example, the base member **35** is made of Inconel. The core portion **36** is made of a material (for example, pure copper) having a coefficient of thermal conductivity higher than that of the base member **35**.

As described above, in the first embodiment, the magnetic substance **210** is disposed in the middle of the conductive path connecting the center electrode **20** and the terminal metal fixture **40** together. Accordingly, it is possible to suppress the occurrence of electromagnetic noise induced by discharge. Further, the conductor **220** is connected in series to at least a part of the magnetic substance **210**. Accordingly, it is possible to suppress an increase in the electrical resistance between the center electrode **20** and the terminal metal fixture **40**. Further, since the conductor **220** is a spiral coil, it is possible to further suppress electromagnetic noise.

A-2. Manufacturing Method

A method of manufacturing the spark plug **100** in the first embodiment can be arbitrarily adopted. For example, the following manufacturing method can be adopted. First, the insulator **10**, the center electrode **20**, the terminal metal fixture **40**, a material powder for each of the conductive sealing portions **60**, **75** and **80**, a material powder for the resistor **70**, and the magnetic substance structure **200** are prepared. The magnetic substance structure **200** is formed by wrapping the conductor **220** around the magnetic substance **210** formed by a well-known method.

Subsequently, the center electrode **20** is inserted into the insulator **10** through an opening (hereinafter, referred to as a "rear opening **14**") of the through hole **12** on the rear end direction D**2** side. As illustrated in FIG. **1**, the center electrode **20** is supported by the reduced inner diameter portion **16** of the insulator **10** such that the center electrode **20** is disposed at a predetermined position in the through hole **12**.

Subsequently, the filling of the material powders for the first conductive sealing portion **60**, the resistor **70**, and the second conductive sealing portion **75** into the through hole **12** and molding of the filled powder materials are performed in the order of the members **60**, **70** and **75**. The filling of the powder materials into the through hole **12** is performed through the rear opening **14**. The molding of the filled powder materials is performed by using a bar inserted through the rear opening **14**. The material powder is molded into substantially the same shape as that of the corresponding member.

Subsequently, the magnetic substance structure **200** is inserted into the through hole **12** through the rear opening **14**, and is disposed on the rear end direction D**2** side of the second conductive sealing portion **75**. The gap between the magnetic substance structure **200** and the inner circumferential surface **10***i* of the insulator **10** is filled with material powder for the covering portion **290**. Subsequently, the filling of material powder for the third conductive sealing portion **80** into the through hole **12** is performed through the rear opening **14**. The insulator **10** is heated up to a predetermined temperature higher than the softening point of a glass component contained in each of the material powders, and the terminal metal fixture **40** is inserted into the through hole **12** through the rear opening **14** of the through hole **12** with the insulator **10** heated at the predetermined temperature. As a result, the material powders are compressed and sintered such that the conductive sealing portions **60**, **75** and **80**, the resistor **70**, and the covering portion **290** are formed.

Subsequently, the metal shell **50** is assembled to the outer circumference of the insulator **10**, and the ground electrode **30** is fixed to the metal shell **50**. Subsequently, the ground electrode **30** is bent, and the manufacturing of a spark plug is complete.

B. Second Embodiment

FIG. **2** is a cross-sectional view of a spark plug **100***b* in a second embodiment. The spark plug **100***b* is different from the spark plug **100** in the first embodiment only in that the magnetic substance structure **200** is replaced with a magnetic substance structure **200***b*. The remainder of the configuration of the spark plug **100***b* is the same as that of the spark plug **100** in FIG. **1**. The same reference signs will be assigned to the same elements in FIG. **2** as those in FIG. **1**, and description thereof will be omitted.

As illustrated, the magnetic substance structure **200***b* is disposed between the resistor **70** and the terminal metal fixture **40** in the through hole **12** of the insulator **10**. On the right side of FIG. **2**, a perspective view (referred to as a "first perspective view P**1**") of the magnetic substance structure **200***b* covered with a covering portion **290***b* and a perspective view (referred to as a "second perspective view P**2**") of the magnetic substance structure **200***b* from which the covering portion **290***b* is removed are illustrated. The second perspective view P**2** illustrates a partially cut-out magnetic substance structure **200***b* so as to show the internal configuration of the magnetic substance structure **200***b*.

As illustrated, the magnetic substance structure **200***b* includes a magnetic substance **210***b* and a conductor **220***b*. The conductor **220***b* is cross-hatched in the second perspective view P**2**. The magnetic substance **210***b* is a tubular member centered around the center axis CL. Similar to the magnetic substance **210** in FIG. **1**, various magnetic materials (for example, a ferromagnetic material containing iron oxide) can be adopted as the material of the magnetic substance **210***b*.

The conductor **220***b* penetrates through the magnetic substance **210***b* along the center axis CL. The conductor **220***b* extends from the end of the magnetic substance **210***b* on the leading end direction D**1** side to the end of the magnetic substance **210***b* on the rear end direction D**2** side. Similar to the conductor **220** in FIG. **1**, various conductive materials (for example, an alloy containing nickel and chromium as main components) can be adopted as the material of the conductor **220***b*.

The outer circumferential surface of the magnetic substance structure **200***b* is covered with the covering portion **290***b* Similar to the covering portion **290** in FIG. **1**, the covering portion **290***b* is a tubular member covering the magnetic substance structure **200***b*. Since the covering portion **290***b* is interposed between the inner circumferential surface **10***i* of the insulator **10** and the outer circumferential surface of the magnetic substance structure **200***b*, the positional offset between the insulator **10** and the magnetic substance structure **200***b* is suppressed. Similar to the covering portion **290** in FIG. **1**, various materials (glass such as borosilicate glass) can be adopted as the material of the covering portion **290***b*.

A second conductive sealing portion **75***b* is disposed between the magnetic substance structure **200***b* and the resistor **70** in the through hole **12** while being in contact with the magnetic substance structure **200***b* and the resistor **70**. A third conductive sealing portion **80***b* is disposed between the magnetic substance structure **200***b* and the terminal metal fixture **40** while being in contact with the magnetic substance structure **200***b* and the terminal metal fixture **40**. Similar to the conductive sealing portions **75** and **80** in FIG. **1**, various conductive materials (for example, a material containing similar glass particles as those of the resistor **70**, and metal particles (Cu, Fe, and the like)) can be adopted as the material of each of the conductive sealing portions **75***b* and **80***b*.

The end of the magnetic substance structure **200***b* on the leading end direction D**1** side, that is, the end of each of the magnetic substance structure **210***b* and the conductor **220***b* on the leading end direction D**1** side is electrically connected to the resistor **70** via the second conductive sealing portion **75***b*. The end of the magnetic substance structure **200***b* on the rear end direction D**2** side, that is, the end of each of the magnetic substance structure **210***b* and the conductor **220***b* on the rear end direction D**2** side is electrically connected to the terminal metal fixture **40** via the third conductive sealing portion **80***b*. The first conductive sealing portion **60**, the resistor **70**, the second conductive sealing portion **75***b*, the magnetic substance structure **200***b*, and the third conductive sealing portion **80***b* form a conductive path through which the center electrode **20** is electrically connected to the terminal metal fixture **40**. It is possible to stabilize the contact resistance between the members **20**, **60**, **70**, **75***b*, **200***b*, **80***b* and **40** stacked on top of each other, and to stabilize the electrical resistance between the center electrode **20** and the terminal metal fixture **40** by using the conductive sealing portions **60**, **75***b* and **80***b*. Hereinafter, all of a plurality of members **60**, **70**, **75***b*, **200***b*, **290***b* and **80***b*, which are disposed in the through hole **12** and connect the center electrode **20** and the terminal metal fixture **40** together, may be referred to as a "connection portion **300***b*".

As described above, in the second embodiment, the magnetic substance **210***b* is disposed in the middle of the conductive path connecting the center electrode **20** and the terminal metal fixture **40** together. Accordingly, it is possible to suppress the occurrence of electromagnetic noise induced by discharge. Further, the conductor **220***b* is connected in series to the magnetic substance **210***b*. Accordingly, it is possible to suppress an increase in the electrical resistance between the center electrode **20** and the terminal metal fixture **40**. Further, the conductor **220***b* is embedded in the magnetic substance **210***b*. That is, the entirety of the conductor **220***b* except for both ends is covered with the magnetic substance **210***b*. Accordingly, it is possible to suppress damage to the conductor **220***b*. For example, the occurrence of a short circuit of the conductor **220***b* induced by vibration can be suppressed.

The spark plug **100***b* in the second embodiment can be manufactured using the same method as the spark plug **100** in the first embodiment. The magnetic substance structure **200***b* is formed by inserting the conductor **220***b* into a through hole of the magnetic substance **210***b* formed by a well-known method.

C. Reference Example

FIG. **3** is a cross-sectional view of a spark plug **100***c* in a reference example. The spark plug **100***c* is used as a reference example in evaluation tests to be described later. The spark plug **100***c* is different from the spark plug **100** in FIG. **1** in that the magnetic substance structures **200** and the third conductive sealing portion **80** are omitted, and is different from the spark plug **100***b* in FIG. **2** in that the magnetic substance structure **200***b* and the third conductive sealing portion **80***b* are omitted. In the reference example, a leg portion **43***c* of a terminal metal fixture **40***c* is longer than the leg portion **43** in the embodiments such that the end of the leg portion **43***c* on the leading end direction D**1** side reaches the vicinity of the resistor **70**. A second conductive sealing portion **75***c* is disposed between the leg portion **43***c* and the resistor **70** while being in contact with the leg portion **43***c* and the resistor **70**. The same material as that of the second conductive sealing portion **75** in the embodiments can be adopted as the material of the second conductive sealing portion **75***c*.

In FIG. **3**, an intermediate position **44** (referred to as an "intermediate position **44**") of a portion of a through hole **12***c* of an insulator **10***c* accommodating the leg portion **43***c* is illustrated. With respect to the through hole **12***c*, an inner diameter of a portion disposed on the rear end direction D**2** side of the intermediate position **44** is slightly larger than an inner diameter of a portion disposed on the leading end direction D**1** side of the intermediate position **44** (particularly, a portion accommodating the first conductive sealing portion **60**, the resistor **70**, the second conductive sealing portion **75***c*, and a portion of the leg portion **43***c*). However, both inner diameters may be the same.

The remainder of the configuration of the spark plug **100***c* in the reference example is the same as those of the spark plugs **100** and **100***b* illustrated in FIGS. **1** and **2**. All of the first conductive sealing portion **60**, the resistor **70**, and the second conductive sealing portion **75***c* form a connection portion **300***c* connecting the center electrode **20** and the terminal metal fixture **40***c* together in the through hole **12***c*. The spark plug **100***c* in the reference example can be manufactured using the same method as the spark plugs **100** and **100***b* in the embodiments.

D. Evaluation Test

D-1. Configuration of Spark Plug Samples

Evaluation tests performed on a plurality of types of spark plug samples will be described. Table 1 below illustrates the configuration of each sample, and each evaluation result of four evaluation tests.

TABLE 1

No.	Configuration	Existence or Non-existence of Covering Portion	Electromagnetic Noise Characteristics	Impact Resistance Characteristics	Resistance Stability	Durability
1	A	Yes	10	10	10	10
2	B	Yes	6	10	10	10
3	C	—	Reference	10	10	10
4	D	Yes	5	10	10	10
5	E	Yes	4	10	10	10
6	A	No	10	5	10	10
7	B	No	6	5	10	10
8	F	Yes	5	10	10	10
9	G	Yes	6	10	10	1
10	H	Yes	8	10	10	10
11	I	Yes	—	0	0	1
12	J	Yes	—	0	0	1
13	K	Yes	10	10	10	10

In the evaluation tests, 13 types of samples with different configurations were evaluated. The table illustrates numbers indicating sample types, reference signs indicating configuration types, the existence or non-existence of a covering portion, the evaluation results of electromagnetic noise characteristics, the evaluation results of impact resistance characteristics, the evaluation results of resistance stability, and the evaluation results of durability.

The correlations between the reference signs indicating the configuration types and the configurations of the spark plugs are as described below.

A: the configuration illustrated in FIG. **1**

B: the configuration illustrated in FIG. **2**

C: the configuration illustrated in FIG. **3**

D: a configuration in which the dispositions of the resistor **70** and the magnetic substance structure **200** in the configuration in FIG. **1** are switched

E: a configuration in which the dispositions of the resistor **70** and the magnetic substance structure **200***b* are switched

F: a configuration in which the magnetic substance **210** in the configuration in FIG. **1** is replaced with a member made of alumina and having the same shape as the magnetic substance **210**

G: a configuration in which the conductor **220***b* in the configuration in FIG. **2** is replaced with a conductor with 2 kΩ resistance

H: configuration in which the conductor **220***b* in the configuration in FIG. **2** is replaced with a conductor with 1 kΩ resistance

I: a configuration in which the third conductive sealing portion **80** is omitted from the configuration in FIG. **1**

J: a configuration in which the second conductive sealing portion **75** is omitted from the configuration in FIG. **1**

K: a configuration in which the conductor **220***b* in the configuration in FIG. **2** is replaced with a conductor with 200 kΩ resistance

Here, as illustrated in Table 1, the existence or non-existence of the covering portions **290**, **290***b* are determined independently from the configurations A to K.

Features common to the configurations A to K are as described below.

1) the material of the resistor **70**: a composite containing B_2O_3—SiO_2 based glass, ZrO_2 as ceramic particles, and C as conductive material

2) the material of the magnetic substances **210**, **210***b*: MnZn ferrite

3) the material of the conductors **220**, **220***b*: an alloy containing nickel and chromium as main components

4) the material of the conductive sealing portions **60**, **75**, **75***b*, **80**, **80***b* and **80***c*: a composite containing B_2O_3—SiO_2 based glass and Cu as metal particles

The electrical resistance of the conductor is the electrical resistance between the end of the conductor on the leading end direction D**1** side and the end of the conductor on the rear end direction D**2** side. Hereinafter, the electrical resistance between the end of the conductor on the leading end direction D**1** side and the end of the conductor on the rear end direction D**2** side is referred to as an end-to-end resistance. Hereinafter, the results of each of the evaluation tests will be described.

D-2. Evaluation Test on Electromagnetic Noise Characteristics

The electromagnetic noise characteristics were evaluated using an insertion loss measured according to the method specified in JASO D002-2. Specifically, the improvement (unit is dB) of the insertion loss at a frequency of 300 MHz when a 3^{rd} sample was used as a datum was adopted as an evaluation result. An evaluation result denoted by "m (m is an integer which is zero or greater and ten or less)" implies that the improvement of the insertion loss with respect to the 3^{rd} sample is m (dB) or greater and less than m+1 (dB). For example, an evaluation result denoted by "5" implies that the improvement is 5 dB or greater and less than 6 dB. An evaluation result was determined to be "10" when the improvement was 10 dB or greater. In the evaluation result, an average value of the insertion losses of five samples with the same configuration was used as the insertion loss of each type of sample. The five samples having the electrical resistance between the center electrode **20** and the terminal metal fixture **40**, **40***c* in a range with a center value of 5 kΩ and a width of 0.6 kΩ, that is, a range of 4.7 kΩ or greater and 5.3 kΩ or less were adopted. Since 11^{th} and 12^{th} samples had a large variation in the electrical resistance, and five samples with the aforementioned range of electrical resistance could not obtained, the 11^{th} and 12^{th} samples were not evaluated.

As illustrated in Table 1, when a 1^{st} sample was compared to an 8^{th} sample, the evaluation result of the 1^{st} sample including the magnetic substance **210** was better than that of the 8^{th} sample from which the magnetic substance **210** was omitted. As such, it was possible to suppress electromagnetic noise by providing the magnetic substance **210**.

The evaluation result of each of the 1^{st} sample and a 6^{th} sample including the coil-shaped conductor **220** was "10" which was the highest grade, and the evaluation result of each of a 2^{nd} sample and a 7^{th} sample including the straight conductor **220***b* was "6" which is less than 10. As such, it was possible to considerably suppress electromagnetic noise by providing the coil-shaped conductor **220**.

When the 1^{st} sample was compared to a 4^{th} sample, the evaluation result of the 1^{st} sample in which the magnetic substance structure **200** was disposed closer to the rear end direction D**2** side than the resistor **70** was better than that of the 4^{th} sample in which the magnetic substance structure **200** was disposed closer to leading end direction D**1** side than the resistor **70**. Similarly, when the 2^{nd} sample was compared to a 5^{th} sample, the evaluation result of the 2^{nd} sample in which the magnetic substance structure **200***b* was disposed closer to the rear end direction D**2** side than the resistor **70** was better than that of the 5^{th} sample in which the magnetic substance structure **200***b* was disposed closer to the leading end direction D**1** side than the resistor **70**. As such, it was possible to suppress electromagnetic noise by disposing the magnetic substance structure on the rear end direction D**2** side of the resistor regardless of the configuration of the magnetic substance structure.

When at least one of the second conductive sealing portion **75** and the third conductive sealing portion **80** interposing the magnetic substance structure **200** therebetween was omitted (the 11^{th} sample and the 12^{th} sample), it was difficult to stabilize the electrical resistance between the center electrode **20** and the terminal metal fixture **40**. In contrast, it was possible to stabilize the electrical resistance by providing the second conductive sealing portion **75** and the third conductive sealing portion **80**.

D-3. Evaluation Result of Impact Resistance Characteristics

The impact resistance characteristics were evaluated according to the impact resistance test specified in 7.4 of JIS B8031:2006. An evaluation result denoted by "0" implies the occurrence of abnormality in the impact resistance test. When no abnormality was observed in the impact resistance test, a vibration test was additionally performed for 30 minutes. The difference between an electrical resistance measured before the evaluation test and an electrical resistance measured after the evaluation test was calculated. The electrical resistance is the electrical resistance between the center electrode **20** and the terminal metal fixture **40**, **40***c*. An evaluation result denoted by "5" implies that an absolute value of the difference between the electrical resistances exceeds 10% of the electrical resistance before the test. An evaluation result denoted by "10" implies that an absolute value of the difference between the electrical resistances is 10% or less of the electrical resistance before the test.

As illustrated in Table 1, the evaluation result of each of the 11th sample and 12th sample, from which at least one of the second conductive sealing portion **75** and the third conductive sealing portion **80** interposing the magnetic substance structure **200** therebetween was omitted, was "0". In contrast, the evaluation results of the 1st to 10th samples and a 13th sample, which include two conductive sealing portions (for example, the conductive sealing portions **75** and **80** in FIG. **1**) interposing the magnetic substance structure **200**, **200***b* therebetween, were "5" or "10" which was better than those of the 11th sample and the 12th sample. As such, by interposing the magnetic substance structure **200**, **200***b* between the two conductive sealing portions, it was possible to improve impact resistance.

Further, the evaluation result of each of the 6th sample and 7th sample, in which the magnetic substance structure **200**, **200***b* was interposed between the two conductive sealing portions but which did not include the covering portion **290**, **290***b*, the evaluation result of each of these samples was "5". In contrast, the evaluation result of each of the 1st to 5th samples, the 8th to 10th samples, and the 13th sample, which include the two conductive sealing portions interposing the magnetic substance structure **200**, **200***b* therebetween and the covering portion **290**, **290***b*, was "10". As such, it was possible to considerably improve the impact resistance by providing the covering portion **290**, **290***b*. However, the covering portion **290**, **290***b* may be omitted.

D-4. Evaluation Result of Resistance Stability

The resistance stability was evaluated based on a standard deviation in the electrical resistances between the center electrode **20** and the terminal metal fixture **40**, **40***c*. As described above, the spark plugs used in the evaluation tests were manufactured by heating the insulator **10** in a state where the material of the connection portion (for example, the connection portion **300** in FIG. **1**) was disposed in the through hole **12**, **12***c*. The powder materials of the conductive sealing portions **60**, **75**, **75***b*, **75***c*, **80**, and **80***b* might flow due to the heating. A variation in the electrical resistance might occur due to the flowing of the powder materials. The magnitude in the variation was evaluated. Specifically, 100 spark plugs with the same configuration were manufactured for each sample type. The electrical resistances between the center electrode **20** and the terminal metal fixture **40**, **40***c* were measured, and a standard deviation in the measured electrical resistances was calculated. An evaluation result denoted by "0" implies that the standard deviation is greater than 0.8, an evaluation result denoted by "5" implies that the standard deviation is greater than 0.5 and 0.8 or less, and an evaluation result denoted by "10" implies that the standard deviation is 0.5 or less.

As illustrated in Table 1, the evaluation result of each of the 11th sample and the 12th sample, from which at least one of the second conductive sealing portion **75** and the third conductive sealing portion **80** interposing the magnetic substance structure **200** therebetween was omitted, was "0". In contrast, the evaluation result of each of the 1st to 10th samples, and the 13th sample, which include the two conductive sealing portions (for example, the conductive sealing portions **75** and **80** in FIG. **1**) interposing the magnetic substance structures **200**, **200***b* therebetween, was "10" which was better than those of the 11th sample and the 12th sample. As such, by interposing the magnetic substance structure **200**, **200***b* between the two conductive sealing portions, it was possible to considerably stabilize the electrical resistance.

D-5. Evaluation Result of Durability

The durability is durability against discharge. The spark plug sample was connected to an automotive transistorized ignition system, and discharge was repeatedly performed under the following conditions so as to evaluate the durability.

Temperature: 350 degrees Celsius

Voltage Applied to Spark Plug: 20 kV

Discharge Period: 3,600 incidences/minute

Operation Time: 100 hours

The evaluation test was performed under the aforementioned conditions, and thereafter, the electrical resistance between the center electrode **20** and the terminal metal fixture **40**, **40***c* was measured at a room temperature. The evaluation result was determined to be "10" when the electrical resistance after the evaluation test was less than 1.5 times the electrical resistance before the evaluation test. The evaluation result was determined to be "1" when the electrical resistance after the evaluation test was greater than or equal to 1.5 times the electrical resistance before the evaluation test.

As illustrated in Table 1, the evaluation result of the 2nd sample including the conductor **220***b* was "10". The evaluation result of the 13th sample including the conductor with 200 kΩ resistance instead of the conductor **220***b* was "10". The evaluation result of the 10th sample including the conductor with 1 kΩ resistance instead of the conductor **220***b* was "10". The evaluation result of the 9th sample including the conductor with 2 kΩ resistance instead of the conductor **220***b* was "1". The end-to-end resistance of the conductor **220***b* was approximately 50 kΩ. As such, it was possible to improve durability against discharge by reducing the end-to-end resistance of the conductor (specifically, the conductor connected to the magnetic substance **210***b*) of the magnetic substance structure.

The reason it was possible to improve durability against discharge by reducing the end-to-end resistance of the conductor of the magnetic substance structure can be estimated as follows. That is, since current flows through the conductor connected to the magnetic substance **210***b* during discharge, the conductor generates heat. The magnitude of current during discharge is adjusted in such a way that a proper spark occurs at the gap g regardless of the internal configuration of the spark plug. Accordingly, the greater the end-to-end resistance of the conductor is, the higher the temperature of the conductor may become. When the temperature of the conductor is increased, a short circuit of the conductor is more likely to occur. When the conductor is short circuited, the electrical resistance between the center electrode **20** and the terminal metal fixture **40** may be increased. In addition, when the temperature of the conductor is increased, the temperature of the magnetic substance **210***b* is also increased. The magnetic substance **210***b* is prone to damage when the temperature of the magnetic substance **210***b* is high compared to when the temperature is low (for example, the cracking of the magnetic substance **210***b* occurs). An increase in the end-to-end resistance of the magnetic substance **210***b* induced by damage to the magnetic substance **210***b* may cause an increase in the electrical resistance between the center electrode **20** and the terminal metal fixture **40**. As described above, the smaller the end-to-end resistance of the conductor is, the further it is possible to suppress the occurrence of damage to the magnetic substance **210***b* and a short circuit of the conductor. As a result, it can be estimated that it is possible to improve durability against discharge. Further, when the end-to-end resistance of the conductor is high, since current flows along the surface of the conductor during discharge, electromagnetic noise may occur. For this reason, the conductor of the magnetic substance structure preferably has a low end-to-end resistance.

The end-to-end resistances of the conductors **220***b* of the 2^{nd}, the 13^{th}, and 10^{th} samples, the evaluation results of which were "10" indicating good durability, were 50 kΩ, 200 kΩ, and 1 kΩ, respectively. An arbitrary value among these values can be adopted as the upper limit of a preferable range (range of a lower limit or greater and an upper limit or less) of the end-to-end resistance of the conductor **220***b*. An arbitrary value less than or equal to the upper limit among these values can be adopted as the lower limit. For example, a value of 1 kΩ or less can be adopted as the end-to-end resistance of the conductor **220***b*. More preferably, a value of 200 kΩ or less can be adopted as the end-to-end resistance of the conductor **220***b*. In addition to the aforementioned values, a value of 0 kΩ can be adopted as the lower limit of the preferable range of the end-to-end resistance of the conductor **220***b*.

The aforementioned description has been given with reference to the evaluation results of the 2^{nd}, the 10^{th}, the 11^{th}, and the 13^{th} samples with the configuration illustrated in FIG. **2**. However, it can be estimated that the relationship between heat generation of the conductor and the likeliness of occurrence of a failure (a short circuit of the conductor or damage to the magnet) can be applied regardless of the configuration of the magnetic substance structure. Accordingly, also in the spark plug with the configuration illustrated in FIG. **1**, it can be estimated that, the lower the end-to-end resistance of the coil-shaped conductor **220** is, the further it is possible to suppress the occurrence of a short circuit of the conductor **220** or damage to the magnetic substance **210** to thus improve durability against discharge. Conductive metal such as an iron material or copper is preferably adopted as the material of the coil-shaped conductor **220**. Particularly, stainless steel or a nickel alloy is preferably adopted upon consideration of heat resistance and costs.

During discharge, current may flow through not only the conductor **220**, **220***b* but also the magnetic substance **210**, **210***b*. Accordingly, the magnetic substance structure **200**, **200***b* which is an assembly of the magnetic substance **210**, **210***b* and the conductor **220**, **200***b* preferably has low end-to-end resistances so as to suppress the occurrence of damage to the magnetic substance **210**, **210***b*. For example, a range of 0 kΩ or greater and 3 kΩ or less can be adopted as a preferable range of the end-to-end resistance of the magnetic substance structure **200**, **200***b*. However, a value greater than 3 kΩ may be adopted. The end-to-end resistances of the conductors of the 2^{nd}, the 13^{th}, and 10^{th} samples, the evaluation results of which showed good durability, were 50 kΩ, 200 kΩ, and 1 kΩ, respectively. When it is taken into consideration that such conductors are adopted, an arbitrary value among these end-to-end resistances can be adopted as the upper limit of the preferable range (range of a lower limit or greater and an upper limit or less) of the end-to-end resistance of the magnetic substance structure **200**, **200***b*. An arbitrary value less than or equal to the upper limit among these values can be adopted as the lower limit. For example, a value of 1 kΩ or less can be adopted as the end-to-end resistance of the magnetic substance structure **200**, **200***b*. More preferably, a value of 200 kΩ or less can be adopted as the end-to-end resistance of the magnetic substance structure **200**, **200***b*. In addition to the aforementioned values, a value of 0 kΩ can be adopted as the lower limit of the preferable range of the end-to-end resistance of the magnetic substance structure **200**, **200***b*.

Preferably, the end-to-end resistance of the conductor **220**, **220***b* is respectively lower than that of the magnetic substance **210**, **210***b* so as to suppress heat generation of the magnetic substance structure **200**, **200***b*. In this configuration, it is possible to reduce the end-to-end resistance of the magnetic substance structure **200**, **200***b* by connecting the conductor **220**, **220***b* to the magnetic substance **210**, **210***b*. As a result, it is possible to suppress heat generation of the magnetic substance structure **200**, **200***b*. In each of the 1^{st} to the 13^{th} samples, the end-to-end resistance of the magnetic substance **210**, **210***b* was several kΩ and was greater than the end-to-end resistance of the conductor (for example, the conductor **220**, **220***b*). As illustrated in Table 1, the evaluation results of the 1^{st} to 8^{th}, the 10^{th}, and the 13^{th} samples showed good durability.

As illustrated in Table 1, the evaluation results of the 11^{th} and the 12^{th} samples, in which at least one of the second conductive sealing portion **75** and the third conductive sealing portion **80** interposing the magnetic substance structure **200** therebetween was omitted, were "1". Each of the 1^{st} to 8^{th}, the 10^{th}, and the 13^{th} samples with a good evaluation result of "10" included two conductive sealing portions (for example, the conductive sealing portions **75** and **80** in FIG. **1**) between which the magnetic substance structure **200**, **200***b* was interposed. As such, since the magnetic substance structure **200**, **200***b* was interposed between the two conductive sealing portions, it was possible to improve durability against discharge.

The following method can be adopted as a method of measuring the end-to-end resistance of the magnetic substance structure of the spark plug. Hereinafter, the spark plugs **100** and **100***b* in FIGS. **1** and **2** will be described as examples. First, an operator disassembles the metal shell **50** from the insulator **10**, cuts the insulator **10** using a cutting tool such as a diamond blade, and takes the connection portion **300**, **300***b* disposed in the through hole **12** out of the through hole **12**. Subsequently, the operator respectively disassembles the conductive sealing portions in contact with the magnetic substance structure **200**, **200***b* from the magnetic substance structure **200**, **200***b* using a cutting tool such as a nippers. Subsequently, after the operator observes the internal structure of each of the covering portion **290**, **290***b* in contact with the magnetic substance structure **200**, **200***b* using a CT scanner, the operator disassembles the covering portion **290**, **290***b* from the magnetic substance structure **200**, **200***b* by cutting and grinding the magnetic substance structure **200**, **200***b*. The operator brings the probes of a resistance meter into contact with both ends (on the leading end direction D**1** side and the rear end direction D**2** side) of the magnetic substance structure **200**, **200***b* obtained in this manner, and measures an end-to-end resistance therebetween.

The following method can be adopted as a method of measuring the end-to-end resistance of the conductor of the magnetic substance structure. That is, the operator acquires the conductor **220**, **220***b* by removing the magnetic substance **210**, **210***b* from the magnetic substance structure **200**, **200***b* obtained by the aforementioned method using a cutting tool such as nippers. The operator brings the probes of a resistance meter into contact with both ends on the leading end direction D**1** side and the rear end direction D**2** side of the conductor **220**, **220***b* obtained in this manner, and measures an end-to-end resistance therebetween.

The following method can be adopted as a method of measuring the end-to-end resistance of the magnetic substance of the magnetic substance structure. That is, after the operator observes the internal structure of the magnetic substance structure **200**, **200***b* using a CT scanner, the operator obtains the magnetic substance **210**, **210***b* by cutting and grinding the magnetic substance structure **200**, **200***b*. The operator brings the probes of a resistance meter into contact with both ends on the leading end direction D**1** side and the rear end direction D**2** side of the magnetic substance **210**, **210***b*, and measures an end-to-end resistance therebetween.

At least one of both ends on the leading end direction D**1** side and the rear end direction D**2** side of each of the magnetic substance structure, the conductor, and the magnetic substance may be a surface. In this case, the minimum end-to-end resistance obtained by bringing the probe of a resistance meter into contact with the surface at an arbitrary position is adopted.

E. Third Embodiment

E-1. Configuration of Spark Plug

FIG. **4** is a cross-sectional view of a spark plug **100***d* in a third embodiment. In the third embodiment, a magnetic substance structure **200***d* is provided instead of the magnetic substance structures **200** and **200***b* in FIGS. **1** and **2**. A perspective view of the magnetic substance structure **200***d* is illustrated on the right side of FIG. **4**. The magnetic substance structure **200***d* is a tubular member centered around the center axis CL. A portion of the center electrode **20** on the rear end direction D**2** side, a first conductive sealing portion **60***d*, a resistor **70***d*, a second conductive sealing portion **75***d*, the magnetic substance structure **200***d*, a third conductive sealing portion **80***d*, and a leg portion **43***d* of a terminal metal fixture **40***d* are disposed in a through hole **12***d* of an insulator **10***d* sequentially from the leading end direction D**1** side toward the rear end direction D**2** side. The magnetic substance structure **200***d* is disposed on the rear end direction D**2** side of the resistor **70***d*. All of the members **60***d*, **70***d*, **75***d*, **200***d* and **80***d* form a connection portion **300***d* connecting the center electrode **20** and the terminal metal fixture **40***d* together in the through hole **12***d*. The remainder of the configuration of the spark plug **100***d* in the third embodiment is substantially the same as the configuration of each of the spark plugs **100** and **100***b* in FIGS. **1** and **2**. In FIG. **4**, the same reference signs will be assigned to portions of the spark plug **100***d* in the third embodiment, which correspond to the portions of each of the spark plugs **100** and **100***b* in FIGS. **1** and **2**. The description thereof will be omitted.

FIG. **5** shows views illustrating the magnetic substance structure **200***d*. A perspective view of the magnetic substance structure **200***d* is illustrated on the left upper side of FIG. **5**. The perspective view illustrates the partially cut-out magnetic substance structure **200***d*. A cross-section **900** in the perspective view is the planar cross-section of the magnetic substance structure **200***d*, which includes the center axis CL. An enlarged schematic view of a portion **800** (hereinafter, referred to as a "target region **800**") of the cross-section **900** is illustrated on the center upper side of FIG. **5**. The target region **800** is a rectangular region having the center axis CL as the center axis, and is formed by two sides parallel with the center axis CL and two sides perpendicular to the center axis CL. The shape of the target region **800** is symmetric with respect to the center axis serving as the symmetric axis CL, that is, the target region **800** has a line-symmetric shape. A first length La in FIG. **5** is a length in a direction perpendicular to the center axis CL of the target region **800**, and a second length Lb is a length parallel with the center axis CL of the target region **800**. The first length La is 1.5 mm, and the second length Lb is 2.0 mm.

As illustrated, the target region **800** (that is, the cross-section of the magnetic substance structure **200***d*) contains a ceramic region **810** and a conductive region **820**. The conductive region **820** is formed by a plurality of grain-shaped regions **825** (hereinafter, referred to as "conductive grain regions **825**" or also simply referred to as "grain regions **825**").

The conductive region **820** is formed of a conductive substance. Carbon, carbon-containing compounds (TiC and the like), perovskite type oxides ($LaMnO_3$ and the like), metal (Cu and the like), or the like can be adopted as the conductive substance. As illustrated, a plurality of conductive grain regions **825** are in contact with each other to form a current path extending from the rear end direction D**2** side toward the leading end direction D**1** side. The plurality of conductive grain regions **825** are formed of a conductive substance powder as the material of the magnetic substance structure **200***d*. For example, one conductive grain region **825** can be formed of one of conductive substance grains contained in the material powder. A plurality of conductive substance grains contained in the material powder stick together to form one conductive grain region **825**.

One conductive grain region **825** illustrates the cross-section of one three-dimensional grain-like region of the conductive substance. Two conductive grain regions **825** may be disposed separately from each other in the target region **800** (that is, the cross-section **900**), which is not illustrated. The two conductive grain regions **825** positioned away from each other in the target region **800** may illustrate the cross-sections of two three-dimensional grain-like regions which are in contact with each other at a position at a front side or a back side of the target region **800**. As such, the plurality of conductive grain regions **825** in contact with each other or positioned away from each other in the target region **800** are capable of forming a current path extending from the rear end direction D**2** side toward the leading end direction D**1** side. During discharge, current flows through the plurality of conductive grain regions **825** in the magnetic substance structure **200***d*.

The ceramic region **810** is formed of a mixed material containing a magnetic substance and a ceramic. An iron-containing oxide (for example, Fe_2O_3) can be adopted as the magnetic substance. For example, a ceramic containing at least one of silicon (Si), boron (B), and phosphorous (P) can be adopted as the ceramic. For example, a ceramic such as glass described in the first embodiment can be adopted. For example, a substance containing one or more oxides arbitrarily selected from silica (SiO_2), boric acid (B_2O_5), and phosphoric acid (P_2O_5) can be adopted as the glass.

As illustrated, the plurality of conductive grain regions **825** are surrounded by the ceramic region **810** containing the magnetic substance. That is, the current path is surrounded by the magnetic substance. When the magnetic substance is disposed in the vicinity of the conductive path, electromagnetic noise induced by discharge is suppressed. For example, the conductive path serves as an inductance element, and suppresses electromagnetic noise. In addition, an increase in the impedance of the conductive path suppresses electromagnetic noise.

One grain region **825** is illustrated on the center lower side of the FIG. **5**. A distance Lm is the maximum grain size (is referred to as the "maximum grain size Lm") of the grain region **825**. The maximum grain size Lm of one grain region **825** is the length of the longest line among lines connecting edges of the grain region **825** together without bulging out of the grain region **825**. The fact that the maximum diameter Lm of each of a plurality of grain regions **825** is large implies that the current path is large. The durability of the current path is improved as the current becomes larger. Accordingly, it is possible to improve the durability of the current path, that is, the durability of the magnetic substance structure **200***d* as the number of conductive grain regions **825** with the maximum grain size Lm (for example, the maximum grain size Lm greater than or equal to 200 μm) among the plurality of grain regions **825** contained in the target region **800** is increased.

When two grain regions **825** are in contact with each other in the target region **800**, the boundary line between the two grain regions **825** may be unclear. In this case, the boundary line can be specified as follows. An enlarged view on the right lower side of FIG. **5** illustrates a contact portion **830** of the two grain regions **825** in contact with each other. When the boundary line is unclear, the contact portion **830** is formed by two protruding portions **812***a* and **812***b* of the ceramic region **810**, which face each other. The shortest straight line BL connecting the two protruding portions **812***a* and **812***b* may be adopted as the boundary line. The maximum grain size Lm can be specified using the boundary line BL.

The ceramic region **810** is formed of a magnetic substance powder and a ceramic powder as the material of the magnetic substance structure **200***d*. Accordingly, pores may be formed in the ceramic region **810** in the target region **800**. An enlarged view of the ceramic region **810** is illustrated on the left lower side of FIG. **5**. As illustrated, pores **812** are formed in the ceramic region **810**. During discharge of the spark plug **100***d*, discharge may partially occur in the pores **812**. The partial discharge occurring in the pores **812** may cause aging of the magnetic substance structure **200***d*, and the occurrence of electromagnetic noise. Accordingly, the proportion of the pores **812** in the magnetic substance structure **200***d* (the proportion of an area of the pores **812** to an area of the remainder of the target region **800** which is other than the conductive region **820**) is preferably small.

E-2. Manufacturing Method

The spark plug **100***d* including the magnetic substance structure **200***d* can be manufactured according to the same sequence as in the manufacturing method described in the first embodiment. The members in the through hole **12***d* of the insulator **10***d* are formed as described below. Material powders for the conductive sealing portions **60***d*, **75***d*, and **80***d*, the resistor **70***d*, and the magnetic substance structure **200***d* are prepared. The same material powders as for the conductive sealing portions **60**, **75**, and **80**, and the resistor **70** in the first embodiment can be adopted as the material powders for the conductive sealing portions **60***d*, **75***d*, and **80***d*, and the resistor **70***d*. For example, the material powder for the magnetic substance structure **200***d* is prepared as described below. A mixed material is prepared by mixing a magnetic substance powder and a ceramic powder. The material powder for the magnetic substance structure **200***d* is prepared by mixing the mixed material with a conductive substance powder.

Subsequently, similar to the manufacturing method in the first embodiment, the center electrode **20** is disposed at a predetermined position in which the center electrode **20** is supported by the reduced inner diameter portion **16** in the through hole **12***d*. The filling of the material powders for the first conductive sealing portion **60***d*, the resistor **70***d*, the second conductive sealing portion **75***d*, the magnetic substance structure **200***d*, and the third conductive sealing portion **80***d* into the through hole **12***d*, and molding of the filled powder materials are performed in the order of the members **60***d*, **70***d*, **75***d*, **200***d*, and **80***d*. The filling of the powder materials into the through hole **12***d* is performed through the rear opening **14**. The molding of the filled powder materials is performed by using a bar inserted through the rear opening **14**. The material powder is molded into substantially the same shape as that of the corresponding member.

The insulator **10***d* is heated up to a predetermined temperature higher than the softening point of a glass constituent contained in each of the material powders, and the terminal metal fixture **40***d* is inserted into the through hole **12***d* through the rear opening **14** of the through hole **12***d* with the insulator **10***d* heated at the predetermined temperature. As a result, each material powder is compressed and sintered such that the conductive sealing portions **60***d*, **75***d*, and **80***d*, the resistor **70***d*, and the magnetic substance structure **200***d* are formed. In the embodiment, the insulator **10***d* is heated to a temperature not causing melting of the conductive substance powder contained in the material of the magnetic substance structure **200***d*. Accordingly, the plurality of conductive grain regions **825** (refer to FIG. **5**) come into a substantially point contact with each other.

F. Evaluation Test

F-1. Outline

Evaluation tests performed on a plurality of types of samples of the spark plug **100***d* in the third embodiment will be described. Tables 2 and 3 below illustrate the configuration of each sample, and each of results of the evaluation tests.

TABLE 2

	Conductive Substance					
No.	Composition	Occupancy (%)	Large Grain Proportion (%) (Lm ≥200 μm)	Fe-containing Oxide	Ceramic Elements Contained	Porosity (%)
A-1	Cr_3C_2	35	40	Fe_2O_3	Si, Mg, Ba, Ca	5.4
A-2	TiC	65	92	Fe_3O_4	P, Mg, Ba, Na	5.6
A-3	C	48	45	$(Ni,Zn)Fe_2O_4$	B, Ca, Mg, P, Na, K	6.1
A-4	$SrTiO_3$	61	51	FeO	Si, P, Mg, Ba, Li	5.3
A-5	$SrCrO_3$	52	55	$BaFe_{12}O_{19}$	B, Ca, Mg, P, Na, K	5.3
A-6	Ti	58	77	$SrFe_{12}O_{19}$	Si, B, Mg, Sr	5.6
A-7	$LaMnO_3$	49	43	$(Ni,Zn)Fe_2O_4$	B, Ca, Mg, P, Na, K	5.6
A-8	$LaCrO_3$	39	45	$NiFe_2O_4$	Si, P, Mg, Ba, Li	5.2
A-9	$LaCoO_3$	44	46	Fe_2O_3	B, Ca, Mg, P, Na, K	5.4
A-10	$LaFeO_3$	48	44	$(Ni,Zn)Fe_2O_4$	Si, B, Mg, Sr	5.7
A-11	$NdMnO_3$	51	42	$(Mn,Zn)Fe_2O_4$	P, Mg, Ba, Na	5.5
A-12	$PrMnO_3$	50	40	$Ba_2Co_2Fe_{12}O_{22}$	B, Ca, Mg, Li	5.2
A-13	$YbMnO_3$	62	41	$(Ni,Zn)Fe_2O_4$	Si, P, Mg, Ba, Li	5.6
A-14	$YMnO_3$	64	43	$CuFe_2O_4$	B, Ca, Mg, P, Na, K	5.3
A-15	Ag	44	95	$CuFe_2O_4$	Si, P, Mg, Ba, Li	5.5
A-16	Cu	47	44	$BaFe_{12}O_{19}$	B, Ca, Mg, P, Na, K	5.1
A-17	Ni	60	57	$SrFe_{12}O_{19}$	Si, B, Mg, Sr	5.6
A-18	Sn	55	83	$NiFe_2O_4$	P, Mg, Ba, Na	5.7
A-19	Fe	59	76	$(Ni,Zn)Fe_2O_4$	B, Ca, Mg, Li	6
A-20	Cr	64	67	$NiFe_2O_4$	Si, P, Mg, Ba, Li	5.4
A-21	Inconel	62	50	$Ba_2Co_2Fe_{12}O_{22}$	B, Ca, Mg, P, Na, K	5.6
A-22	Sendust	65	55	$Y_3Fe_5O_{12}$	P, Mg, Ca, Ti, K, Li	5.8
A-23	Permalloy	40	71	$(Mn,Zn)Fe_2O_4$	P, Mg, Ba, Na	5.5
A-24	$NdMnO_3$	58	55	$(Ni,Zn)Fe_2O_4$	Si, B, Mg, Sr	5
A-25	$PrMnO_3$	46	63	$(Mn,Zn)Fe_2O_4$	P, Mg, Ba, Na	4.4
A-26	$YbMnO_3$	52	71	$Ba_2Co_2Fe_{12}O_{22}$	B, Ca, Mg, Li	4.3
A-27	$YMnO_3$	58	59	$(Ni,Zn)Fe_2O_4$	Si, P, Mg, Ba, Li	3.8
A-28	Fe	64	52	$BaFe_{12}O_{19}$	B, Ca, Mg, P, Na, K	3.5
A-29	Cr	61	66	$SrFe_{12}O_{19}$	Si, P, Mg, Ba, Li	3.3
A-30	Inconel	56	61	$NiFe_2O_4$	B, Ca, Mg, P, Na, K	3.2

	Noise (dB) Before Durability Test				Noise (dB) After Durability Test			
No.	30 MHz	100 MHz	300 MHz	500 MHz	30 MHz	100 MHz	300 MHz	500 MHz
A-1	76	70	64	60	86	80	74	70
A-2	75	70	64	59	84	79	73	68
A-3	75	71	62	59	86	82	73	70
A-4	74	69	63	60	84	79	73	70
A-5	76	70	65	59	85	79	74	68
A-6	75	71	64	58	86	82	75	69
A-7	68	62	58	50	75	69	65	57
A-8	69	61	57	51	75	67	63	57
A-9	69	63	59	51	75	69	65	57
A-10	68	62	58	50	75	69	65	57
A-11	67	62	57	51	74	69	64	58
A-12	69	63	57	52	75	69	63	58
A-13	67	61	58	51	73	67	64	57
A-14	68	61	56	52	74	67	62	58
A-15	67	61	58	51	74	68	65	58
A-16	68	62	56	51	74	68	62	57
A-17	66	61	57	51	72	67	63	57
A-18	67	61	56	50	74	68	63	57
A-19	68	61	58	51	75	68	65	58
A-20	66	62	56	51	72	68	62	57
A-21	68	62	57	51	74	68	63	57
A-22	66	63	57	50	72	69	63	56
A-23	68	61	56	51	75	68	63	58
A-24	60	55	48	43	63	58	51	46
A-25	61	54	49	44	65	58	53	48
A-26	59	55	49	43	61	57	51	45
A-27	60	53	48	43	63	56	51	46
A-28	59	54	48	42	63	58	52	46
A-29	59	55	49	43	61	57	51	45
A-30	58	53	47	44	61	56	50	47

TABLE 3

	Conductive Substance						Noise (dB) Before Durability Test				Noise (dB) After Durability Test			
No.	Composition	Occupancy (%)	Large Grain Proportion (%) (Lm ≥200 μm)	Fe-containing Oxide	Ceramic Elements Contained	Porosity (%)	30 MHz	100 MHz	300 MHz	500 MHz	30 MHz	100 MHz	300 MHz	500 MHz
B-1	C	34	55	$(Ni,Zn)Fe_2O_4$	Si, Mg, Ba, Ca	5.9	80	74	69	65	95	89	85	81
B-2	TiC	67	52	Fe_3O_4	P, Mg, Ba, Na	5.6	83	78	73	68	98	89	85	81
B-3	C	48	45	Non-existence	B, Ca, Mg, P, Na, K	6.1	88	83	78	74	98	93	87	83
B-4	$SrTiO_3$	61	39	$(Ni,Zn)Fe_2O_4$	Si, P, Mg, Ba, Li	5.3	85	80	75	70	100	91	87	83
B-5	Non-existence	—	—	$BaFe_{12}O_{19}$	B, Ca, Mg, P, Na, K	5.3	—	—	—	—	—	—	—	—

In the evaluation tests, 35 types of samples including A-1 to A-30 samples and B-1 to B-5 samples, in which the properties of the magnetic substance structures **200***d* are different from each other, were evaluated. Tables 2 and 3 illustrate sample numbers, the properties (here, the properties of a conductive substance, the properties of an iron-containing oxide, elements contained in the ceramic, and porosity) of the magnetic substance structure **200***d*, and noise test results before and after durability tests. The remainder of the configurations of the 35 types of samples of the spark plug **100***d* was the same except for the properties of the magnetic substance structure **200***d*. For example, the magnetic substance structures **200***d* in the 35 types of samples had substantially the same shape. The magnetic substance structure **200***d* had an outer diameter (that is, the inner diameter of a portion of the through hole **12***d* which accommodated the magnetic substance structure **200***d*) of 3.9 mm.

The composition of the conductive substance, occupancy, and a large grain proportion are illustrated as the properties of the conductive substance. The composition of the conductive substance was specified from the material of the conductive substance. The occupancy is a proportion of the total area of the conductive region **820** in the target region **800** to the total area of the target region **800** illustrated in FIG. **5**. The occupancy was calculated as follows. The magnetic substance structure **200***d* of each of the samples was cut along a plane including the center axis CL, and the cross-section of the magnetic substance structure **200***d* was mirror-polished. A region containing a 1.5 mm×2.0 mm region corresponding to the target region **800** (refer to FIG. **5**) on the cross-section was analyzed using an electron probe microanalyzer (EPMA). Conditions for the EPMA analysis were set as follows. That is, the acceleration voltage of the EPMA was set to 15.0 kV, the working distance was set to 11.0 mm, and a beam diameter was set to 50 μm. The conductive region **820** was specified by image processing of adopting a region, in which the elements of the conductive substance were detected by the EPMA analysis, as the conductive region **820**. An image illustrating the conductive region **820** as illustrated in the target region **800** on the center upper side of the FIG. **5** was acquired by this image processing. The occupancy was calculated by analyzing this image.

The large grain proportion is a proportion of the total number of grain regions **825** with the maximum grain size Lm of 200 μm or greater to the total number of grain regions **825** in the target region **800** (refer to FIG. **5**). The plurality of grain regions **825** in the target region **800** were specified by using the conductive region **820** specified by the EPMA analysis and the image processing. When only a portion of one grain region **825** was positioned in the target region **800**, that is, a portion of one grain region **825** protruded out of the target region **800**, the one grain region **825** was treated as one grain region **825** present in the target region **800** in counting the number of grain regions **825**.

The composition of the iron-containing oxide was specified from the material of the magnetic substance structure **200***d*.

The elements contained in the ceramic were specified from the elements contained in the ceramic material (in these evaluation tests, an amorphous glass material). The tables 2 and 3 illustrate elements other than oxygen. For example, when "SiO_2" is used as the ceramic material, "Si" without denotation of oxygen (O) is illustrated. Various additive components may be added to the ceramic material. Tables 2 and 3 illustrate these additive component elements (for example, Ca and Na). Elements contained in the ceramic region **810** can be specified by EPMA analysis.

The porosity is a proportion of an area the pores **812** (refer to FIG. **5**) to an area of the remainder of the target region **800** which is other than the conductive region **820**. The porosity was calculated as follows. An image of the region equivalent to the target region **800** (refer to FIG. **5**) used in the EPMA analysis was captured using a scanning electron microscope (SEM), with the region being present on the same polished surface used in the EPMA analysis. The obtained SEM images were binarized using image analysis software (Analysis Five manufactured by Soft Imaging System GmbH). A threshold value for the binarization was set as follows.

(1) An operator defined the position of a grain boundary by confirming a secondary electron image and a backscattered electron image on the SEM image, and drawing a line along a dark boundary (equivalent to the grain boundary) in the backscattered electron image.

(2) In order to improve the backscattered electron image, the operator smoothened the backscattered electron image while maintaining the edge of the grain boundary.

(3) The operator made a graph from the backscattered electron image with the graph showing brightness on the horizontal axis and an incidence on the vertical axis. The

obtained graph was a bimodal graph. The brightness of a middle point between two peaks was set as the threshold value for binarization.

The pores **812** in the ceramic region **810** were specified by the binarization. Differentiation between the ceramic region **810** and the conductive region **820** on the SEM image was made by the EPMA analysis. The proportion of the area of the pores **812** to the area of the remainder of the target region **800** other than the conductive region **820** was calculated as the porosity.

An average value of 10 values obtained by analyzing 10 cross-sectional images of the magnetic substance structure **200***d* was adopted as the occupancy, the large grain proportion, the porosity, and the like. Ten cross-sectional images of one type of samples were captured using 10 cross-sections of 10 samples of the same type which were manufactured under the same conditions.

In a noise test, a noise intensity was measured according to "automotive—radio noise characteristics—section 2: measurement method of preventive device, current method" of Japanese Automotive Standards Organization D-002-2 (JASO D-002-2). Specifically, the distance of the gap g of the spark plug sample was adjusted to 0.9 mm±0.01 mm, a voltage in a range of from 13 kV to 16 kV was applied to the sample, and discharge was performed. Current flowing through the terminal metal fixture **40***d* during discharge was measured using a current probe, and the measured value was converted into the unit of dB for comparison. Noise at four types of frequencies, that is, 30 MHz, 100 MHz, 300 MHz, and 500 MHz was measured. Each numerical value in the tables denotes a noise intensity with respect to a predetermined reference. The noise intensity becomes high as the numerical value becomes larger. A "before durability test" denotes a noise test result before a durability test to be described later is performed, and an "after durability test" denotes a noise test result after the durability test is performed. The durability test is a test in which the spark plug samples are discharged with a discharge voltage of 20 kV at a temperature of 200 degrees Celsius for 400 hours. The durability test may cause the progress of the aging of the magnetic substance structure **200***d*. A noise intensity "after the durability test" may be higher than a noise intensity "before the durability test" due to the progress of the aging of the magnetic substance structure **200***d*.

As illustrated in Tables 2 and 3, both of the noise intensities after and before the durability test became lower as the frequency became higher.

F-2. Regarding Occupancy of Conductive Substance

The occupancy of the conductive substance in each of the A-1 to A-6 samples in Table 2 was in a range of 35% or greater and 65% or less. In the A-1 to A-6 samples, it was possible to realize a sufficiently low noise intensity of 76 dB or less at all of the frequencies before the durability test. A noise intensity even after the durability test was less than or equal to 86 dB at all of the frequencies, and it was possible to suppress an increase in the noise intensity. That is, it was possible to realize good durability of the magnetic substance structure **200***d*. The increased amounts of noise intensity at all of the frequencies induced by the durability test were in a range of 9 dB or greater and 11 dB or less.

The occupancy of the B-1 sample in Table 3 was 34% (the large grain proportion was 55%) which was less than the occupancy of each of the A-1 to A-6 samples. Before and after the durability test, the noise intensities of the B-1 sample were higher than those of an arbitrary sample of the A-1 to A-6 samples at the same frequency. The difference in noise intensity at the same frequency between the B-1 sample and an arbitrary sample of the A-1 to A-6 samples was greater than or equal to 3 dB before the durability test, and was greater than or equal to 7 dB after the durability test.

The increased amounts of the noise intensity of the B-1 sample induced by the durability test were 15 dB (at 30 MHz and 100 MHz) and 16 dB (at 300 MHz and 500 MHz). The increased amounts (9 dB, 10 dB, and 11 dB) of noise intensity of the A-1 to A-6 samples were less by approximately 5 dB than the increased amount (15 dB and 16 dB) of noise intensity of the B-1 sample at the same frequency. That is, the A-1 to A-6 samples with relatively high occupancy were capable of realizing good durability compared to the B-1 sample with relatively low occupancy. The estimated reason for this is that when the occupancy is high, the current path formed by the conductive region **820** (refer to FIG. **5**) is large, and a large number of current paths are formed by the conductive region **820** compared to when the occupancy is low.

The occupancy of the conductive substance of the B-2 sample in Table 3 was 67% (the large grain proportion was 52%) which was greater than the occupancy of the conductive substance of each of the A-1 to A-6 samples. Before the durability test, the noise intensity of the B-2 sample was higher than that of an arbitrary sample of the B-1 sample and the A-1 to A-6 samples at the same frequency. After the durability test, the noise intensity of the B-2 sample was approximately equal to that of the B-1 sample at the same frequency, and was higher than that of an arbitrary sample of the A-1 to A-6 samples at the same frequency. As such, the A-1 to A-6 samples with relatively low occupancy were capable of suppressing noise compared to the B-2 sample with relatively high occupancy. The estimated reason for this is that the distribution region of the conductor (the iron-containing oxide) in the vicinity of the conductive path becomes increased as the occupancy of the conductive substance becomes lower.

The occupancy of the conductive substances of the A-1 to A-6 samples realizing good durability while suppressing noise were 35%, 48%, 52%, 58%, 61%, and 65%. An arbitrary value among these six values can be adopted as the upper limit of a preferable range (range of a lower limit or greater and an upper limit or less) of the occupancy. An arbitrary value less than or equal to the upper limit among these values can be adopted as the lower limit. For example, a value in a range of 35% or greater and 65% or less can be adopted as the occupancy.

An arbitrary method can be adopted as a method of adjusting the occupancy. For example, it is possible to increase the occupancy by increasing the percent (weight percent) of the conductive substance in the material of the magnetic substance structure **200***d*.

F-3. Regarding Large Grain Proportion

The large grain proportion of the conductive substance of each of the A-1 to A-6 samples in Table 2 was greater than or equal to 40%. As described above, the A-1 to A-6 samples were capable of realizing good durability while suppressing noise. The large grain proportion of the conductive substance of the B-4 sample in Table 3 was 39% (the occupancy was 61%) which was less than that of each of the A-1 to A-6 samples. Before and after the durability test, the noise intensities of the B-2 sample were higher than those of an arbitrary sample of the A-1 to A-6 samples at the same frequency. Before and after the durability test, the difference between the noise intensities of the B-2 sample were higher than those of an arbitrary sample of the A-1 to A-6 samples at the same frequency. the difference in noise intensity between an arbitrary sample of the A-1 to A-6 samples and the B-4 sample was greater than or equal to 9 dB.

The increased amounts of the noise intensity of the B-4 sample induced by the durability test were 15 dB (at 30 MHz), 11 dB (at 100 MHz), 12 dB (at 300 MHz), and 13 dB (at 500 MHz). The increased amounts of noise intensity of an arbitrary sample of the A-1 to A-6 samples at 30 MHz, 300 MHz, and 500 MHz were less than the increased amounts of noise intensity of the B-4 sample at the same frequency. The increased amount (11 dB) of noise intensity of each of the A-3 and A-6 samples at 100 MHz was equal to that of the B-4 sample. The increased amount of noise intensity of an arbitrary sample of the A-1, the A-2, the A-4, and the A-5 samples at 100 MHz was less than the increased amount (11 dB) of noise intensity of the B-4 sample. As such, the A-1 to A-6 samples with a relatively high large grain proportion were capable of realizing good durability compared to the B-4 sample with a relatively low large grain proportion. The estimated reason for this is that when the large grain proportion is high, the current path formed by the conductive region **820** (refer to FIG. **5**) is large compared to when the large grain proportion is low.

The large grain proportion of the conductive substances of the A-1 to A-6 samples realizing good durability while suppressing noise were 40%, 45%, 51%, 55%, 77%, and 92%. An arbitrary value among these six values can be adopted as the upper limit of a preferable range (range of a lower limit or greater and an upper limit or less) of the large grain proportion. An arbitrary value less than or equal to the upper limit among these values can be adopted as the lower limit. For example, a value in a range of 40% or greater and 92% or less can be adopted as the large grain proportion. It is estimated that even if the large grain proportion is a larger value (for example, 100%), it is possible to suppress noise by setting the occupancy of the conductive substance in the aforementioned preferable range. Accordingly, 100% may be adopted as the upper limit of the preferable range of the large grain proportion. For example, an arbitrary value greater than or equal to 40% can be adopted as the large grain proportion.

An arbitrary method can be adopted as a method of adjusting the large grain proportion. For example, it is possible to increase the large grain proportion by increasing the particle size of the material powder of the conductive substance. A binder may be added to and mixed with the material powder of the conductive substance before the material powder of the conductive substance is mixed with other materials. Accordingly, a plurality of conductive material grains are stuck together by the binder, thereby resulting in formation of grain-like portions having a large diameter. As a result, it is possible to increase the large grain proportion.

F-4. Regarding Occupancy and Large Grain Proportion of Conductive Substance, and Material of Magnetic Substance Structure **200*d***

The following materials were used to manufacture the A-1 to A-6 samples realizing good durability while suppressing noise. A material selected from the following materials was used as the conductive substance of the magnetic substance structure **200*d***: carbon (C), carbon oxides (Cr_3C_2 and TiC), perovskite type oxides ($SrTiO_3$ and $SrCrO_3$), and metal (titanium (Ti)). A material selected from the following materials was used as the magnetic substance of the magnetic substance structure **200*d***: iron oxides (Fe_2O_3, Fe_3O_4, and FeO), a spinel ferrite ((Ni, Zn)Fe_2O_4), and hexagonal ferrites ($BaFe_{12}O_{19}$ and $SrFe_{12}O_{19}$). The ceramic of the magnetic substance structure **200*d*** contained at least one of silicon (Si), boron (B), and phosphorous (P).

Typically, in many cases, when the type of a second material is the same as that of a first material, the second material has similar characteristics as those of the first material. Accordingly, it is estimated that even if other materials of the same type are used instead of the aforementioned materials of the magnetic substance structure **200*d***, the aforementioned preferable ranges can be applied to a preferable range of the occupancy of the conductive substance, and a preferable range of the large grain proportion of the conductive substance. For example, it is estimated that when the magnetic substance structure **200*d*** has any one of the following properties Z1 to Z3, the preferable range of the occupancy and the preferable range of the large grain proportion can be applied.

[Properties Z1] The magnetic substance structure **200*d*** contains a conductive substance as a conductor.

[Properties Z2] The magnetic substance structure **200*d*** contains an iron-containing oxide as a magnetic substance.

[Properties Z3] The magnetic substance structure **200*d*** contains ceramic containing at least one of silicon (Si), boron (B), and phosphorous (P).

The conductive substance contained in the magnetic substance structure **200*d*** preferably contains at least one of carbon, a carbon dioxide, a perovskite type oxide, and metal. However, other conductive substances may be adopted.

F-5. Regarding Type of Perovskite Type Oxide

The A-7 to A-14 samples in Table 2 were samples using various perovskite type oxides as conductive substances. Specifically, the conductive substances were $LaMnO_3$, $LaCrO_3$, $LaCoO_3$, $LaFeO_3NdMnO_3$, $PrMnO_3$, $YbMnO_3$, and $YMnO_3$ in the order of the A-7 to A-14 samples. These oxides are represented by general formula ABO_3. A leading element A (for example, "La" of $LaMnO_3$) is an A-site element, and a subsequent element B (for example, "Mn" of $LaMnO_3$) is a B-site element. When a cubic crystal has a non-distorted crystal structure, a B site is a 6-coordinated site, and is surrounded by an octahedron formed of oxygen. An A site is a 12-coordinated site.

The occupancy of the conductive substance of each of the A-7 to A-14 samples was 39% or greater and 64% or less. The large grain proportion was greater than or equal to 40%. The magnetic substances were (Ni,Zn)Fe_2O_4, $NiFe_2O_4$, Fe_2O_3, (Ni,Zn)Fe_2O_4, (Mn,Zn)Fe_2O_4, $Ba_2Co_2Fe_{12}O_{22}$, (Ni, Zn)Fe_2O_4, and $CuFe_2O_4$ in the order of the sample numbers. The ceramic of the magnetic substance structure **200*d*** contained at least one of Si, B, and P.

As illustrated in Table 2, before and after the durability test, the noise intensities of the A-7 to A-14 samples were lower than those of an arbitrary sample of the A-1 and A-6 samples at the same frequency. As such, it was possible to further suppress noise by using perovskite type oxides as the conductive substances of the A-7 to A-14 samples.

The increased amount of noise intensity of each of the A-7 to A-14 samples induced by the durability test was 6 dB or 7 dB. In contrast, the increased amounts of noise intensity of the A-1 to A-6 samples induced by the durability test were 9 dB or greater and 11 dB or less, and were greater than those of the A-7 to A-14 samples. As such, it was possible to improve the durability of the magnetic substance structure **200***d* by using perovskite type oxides as the conductive substances of the A-7 to A-14 samples. The estimated reason for this is that the perovskite type oxides of the A-7 to A-14 samples have low electrical resistance and are stable.

The perovskite type oxides of the A-4 and A-5 samples had the same A-site element (Sr), and different B-site elements (Ti and Cr). The A-4 and A-5 samples had a small difference (less than or equal to 2 dB) in noise intensity at the same frequency before the durability test, and also had a small difference (less than or equal to 2 dB) in noise intensity at the same frequency after the durability test. That is, the A-4 and A-5 samples having the same A-site element were capable of realizing the same level of noise suppression capability and the same level of durability.

The A-7 to A-10 samples had the same A-site element (La), and different B-site elements (Mn, Cr, Co, and Fe). The A-7 to A-10 samples had a small difference (less than or equal to 2 dB) in noise intensity at the same frequency before the durability test, and also had a small difference (less than or equal to 2 dB) in noise intensity at the same frequency after the durability test. That is, the A-7 to A-10 samples having the same A-site element were capable of realizing the same level of noise suppression capability and the same level of durability.

It is estimated that it is possible to realize the same level of noise suppression capability and the same level of durability by adopting a plurality of types of perovskite type oxides which have the same A-site element in spite of having different B-site elements. For example, the A-site element of the A-7 to A-14 samples is selected from La, Nd, Pr, Yb, and Y. It is estimated that when the conductive substance of the magnetic substance structure **200***d* contains a perovskite type oxide, the A-site element of which is at least one of La, Nd, Pr, Yb, and Y, similar to the A-7 to A-14 samples, it is possible to suppress noise, and to realize good durability. An oxide having a plurality of types of A-site elements may be adopted as a perovskite type oxide. The conductive substance may contain a plurality of types of perovskite type oxides.

When the material of the conductive substance of the magnetic substance structure **200***d* is unknown, the A-site element of the perovskite type oxide contained in the magnetic substance structure **200***d* of the sample can be specified as follows. For example, the crystal phase of the perovskite type oxide may be specified, and the crystal structure of the specified crystal phase and elements may be specified by analyzing the magnetic substance structure **200***d* using a micro X-ray diffraction method.

F-6. Regarding Type of Metal

The A-15 to A-23 samples in Table 2 were samples using various metals (including alloys) as conductive substances. Specifically, the conductive substances were Ag, Cu, Ni, Sn, Fe, Cr, Inconel, a sendust, and a permalloy in the order of the A-15 to A-23 samples.

The occupancy of the conductive substance of each of the A-15 to A-23 samples was 40% or greater and 65% or less. The large grain proportion was greater than or equal to 44%. The magnetic substances were $CuFe_2O_4$, $BaFe_{12}O_{19}$, $SrFe_{12}O_{19}$, $NiFe_2O_4$, $(Ni,Zn)Fe_2O_4$, $NiFe_2O_4$, $Ba_2Co_2Fe_{12}O_{22}$, $Y_3Fe_5O_{12}$, and $(Mn, Zn)Fe_2O_4$ in the order of the sample numbers. The ceramic of the magnetic substance structure **200***d* contained at least one of Si, B, and P.

As illustrated in Table 2, before and after the durability test, the noise intensities of the A-15 to A-23 samples were lower than those of an arbitrary sample of the A-1 and A-6 samples at the same frequency. As such, it was possible to further suppress noise by using metals as the conductive substances of the A-15 to A-23 samples.

The increased amount of noise intensity of each of the A-15 to A-23 samples induced by the durability test was 6 dB or 7 dB. In contrast, the increased amounts of noise intensity of the A-1 to A-6 samples induced by the durability test were 9 dB or greater and 11 dB or less, and were greater than those of the A-15 to A-23 samples. As such, it was possible to improve the durability of the magnetic substance structure **200***d* by using metals as the conductive substances of the A-15 to A-23 samples. The estimated reason for this is that the metal of each of the A-15 to A-23 samples has good oxidation resistance.

When metal is adopted as a conductive substance, at least one of the metals used in the A-15 to A-23 samples is preferably adopted. For example, a conductive substance preferably contains at least one of Ag, Cu, Ni, Sn, Fe, and Cr. Metals contained in the conductive region **820** of the magnetic substance structure **200***d* can be specified by EPMA analysis.

F-7. Regarding Porosity

The porosity of each of the A-1 to A-6 samples in Table 2 was in a range of 5.3% or greater and 6.1% or less. As described above, the A-1 to A-6 samples were capable of suppressing noise, and realizing good durability. The porosity of each of the A-7 to A-23 samples was in a range of 5.1% or greater and 6% or less. As described above, the A-7 to A-23 samples were capable of further suppressing noise, and realizing better durability.

The porosities of the A-24 and A-30 samples were lower than those of the A-1 to A-23 samples. Specifically, the porosity of each of the A-24 to A-30 samples was in a range of 3.2% or greater and 5% or less. The conductive substances of the A-24 to A-30 samples were $NdMnO_3$, $PrMnO_3$, $YbMnO_3$, $YMnO_3$, Fe, Cr, and Inconel in the order of the sample numbers. The occupancy of the conductive substance was 46% or greater and 64% or less. The large grain proportion was greater than or equal to 52%. The magnetic substances were $(Ni,Zn)Fe_2O_4$, $(Mn,Zn)Fe_2O_4$, $Ba_2CO_2Fe_{12}O_{22}$, $(Ni,Zn)Fe_2O_4$, $BaFe_{12}O_{19}$, $SrFe_{12}O_{19}$, and $NiFe_2O_4$ in the order of the sample numbers. The ceramic of the magnetic substance structure **200***d* contained at least one of Si, B, and P.

As illustrated in Table 2, before and after the durability test, the noise intensities of an arbitrary sample of the A-24 to A-30 samples were lower than those of an arbitrary sample of the A-1 to A-23 samples at the same frequency. As such, the A-24 to A-30 samples with relatively low porosities were capable of suppressing noise compared to the A-1 to A-6 samples and the A-7 to A-23 samples with relatively high porosities. The estimated reason for this is that when the porosity is low, the occurrence of partial discharge in the pore **812** (refer to FIG. **5**) is suppressed compared to when the porosity is high.

The increased amounts of the noise intensity of the A-24 to A-30 samples induced by the durability test were in a range of 2 dB or greater and 4 dB or less. In contrast, the increased amounts of noise intensity of the A-1 to A-6 samples were 9 dB or greater and 11 dB or less, and the increased amount of noise intensity of each of the A-7 to A-23 samples was 6 dB or 7 dB. As such, the A-24 to A-30 samples with a relatively low porosity were capable of realizing good durability compared to the A-1 to A-6 samples and the A-7 to A-23 samples with a relatively high porosity. The estimated reason for this is that when the porosity is low, the occurrence of partial discharge in the pores **812** (refer to FIG. **5**) is suppressed compared to when the porosity is high.

The porosities of the A-1 to A-30 samples realizing good durability while suppressing noise were 3.2%, 3.3%, 3.5%, 3.8%, 4.3%, 4.4%, 5%, 5.1%, 5.2%, 5.3%, 5.4%, 5.5%, 5.6%, 5.7%, 5.8%, 6%, and 6.1%. An arbitrary value among these 17 values can be adopted as the upper limit of a preferable range (range of a lower limit or greater and an upper limit or less) of the porosity. An arbitrary value less than or equal to the upper limit among these values can be adopted as the lower limit. For example, a value in a range of 3.2% or greater and 6.1% or less can be adopted as the porosity.

As described above, the A-24 to A-30 samples were capable of suppressing noise, and durability of the A-24 to A-30 samples could be improved compared to the A-1 to A-23 samples. The porosities of the A-24 to A-30 were 3.2%, 3.3%, 3.5%, 3.8%, 4.3%, 4.4% and 5%. When the upper limit and the lower limit of a preferable range are selected from these seven values, it is possible to further improve noise suppression capability and durability. For example, a value in a range of 3.2% or greater and 5% or less can be adopted as the porosity.

It is estimated that the noise suppression capability and the durability become better as the porosity becomes lower. Accordingly, 0% may be adopted as the lower limit of the porosity. For example, preferably, the porosity is 0% or greater and 6.1% or less, and more preferably, is 0% or greater and 5% or less.

The noise suppression capability of the A-1 to A-6 samples is good compared to the capability of typical spark plugs (for example, spark plug from which the magnetic substance structure **200***d* is omitted). Accordingly, it is estimated that even if the porosity is higher, it is possible to realize practical noise suppression capability. As a result, it is estimated that a higher value (for example, 10%) can be adopted as the upper limit of the porosity.

An arbitrary method can be adopted as a method of adjusting the porosity. For example, when the firing temperature (heating temperature of the insulator **10***d* accommodating the material of the connection portions **300***d* in the through hole **12***d*) of the magnetic substance structure **200***d* is increased, the ceramic material of the magnetic substance structure **200***d* is easily melted, and thus it is possible to reduce the porosity. It is possible to block the pores **812**, and to reduce the porosity by increasing force which is applied to the terminal metal fixture **40***d* when the terminal metal fixture **40***d* is inserted into the through hole **12***d*. It is possible to reduce the porosity by reducing the particle size of the ceramic material of the magnetic substance structure **200***d*.

F-8. Regarding Conductive Substance

The B-5 sample in Table 3 was a sample in which a conductive substance was omitted from the magnetic substance structure **200***d*. The electromagnetic noise of the B-5 sample was too strong, and thus it was possible to measure an exact value of the electromagnetic noise. The estimated reason for this is that current is not capable of smoothly flowing through the magnetic substance structure **200***d*, and partial discharge occurs in the magnetic substance structure **200***d*. In contrast, the A-1 to A-30 were capable of suppressing noise. As such, it was possible to suppress noise by making the magnetic substance structure **200***d* containing the conductive substance. It is estimated that conductive substances capable of suppressing electromagnetic noise are not limited to the conductive substances contained in the samples in Table 2, and various types of conductive substances can be adopted. A conductive substance having good oxidation resistance is preferably adopted so as to realize good durability of the magnetic substance structure **200***d*. It is possible to suppress aging caused by heat generation resulting from the flow of large current by adopting a conductive substance with an electrical resistivity of 50 Ω·m or less.

F-9. Regarding Iron-containing Oxide

The B-3 sample in Table 3 was a sample in which an iron-containing oxide (that is, a magnetic substance) was omitted from the magnetic substance structure **200***d*. As illustrated in Tables 2 and 3, noise intensities of the A-1 to A-30 samples containing the iron-containing oxide were lower than the noise intensity of the B-3 sample at the same frequency. As such, it was possible to suppress noise by making the magnetic substance structure **200***d* containing the iron-containing oxide. The reason for this is that electromagnetic noise is suppressed by the magnetic substance disposed in the vicinity of the current path. Iron-containing oxides containing at least one of FeO, Fe_2O_3, Fe_3O_4, Ni, Mn, Cu, Sr, Ba, Zn, and Y can adopted as the iron-containing oxides of the A-1 to A-30 samples. It is estimated that iron-containing oxides capable of suppressing electromagnetic noise are not limited to the iron-containing oxides contained in the samples in Table 2, and various types of iron-containing oxides (for example, various ferrites) can be adopted.

F-10. Regarding Ceramic

The ceramic contained in the magnetic substance structure **200***d* supports the conductive substance and the magnetic substance (iron-containing oxide). Various ceramics can be adopted as the ceramic supporting the conductive substance and the magnetic substance. For example, amorphous ceramic may be adopted. Glass containing one or more components arbitrarily selected from SiO_2, B_2O_3, P_2O_5, and the like can be adopted as the amorphous ceramic. Instead, crystalline ceramic may be adopted. Crystallized glass (also referred to as glass ceramic) such as Li_2O—Al_2O_3—SiO_2 glass may be adopted as the crystalline ceramic. In any case, it is estimated that it is possible to realize proper noise suppression capability and proper durability by adopting a ceramic containing at least one of silicon (Si), boron (B), and phosphorous (P) as with the A-1 to A-30 samples in Table 2.

E. Modification Example

(1) The material of the magnetic substances **210** and **210***b* is not limited to a MnZn ferrite, and various magnetic materials can be adopted. For example, various ferromagnetic materials can be adopted. The ferromagnetic material is a material which is spontaneously magnetized. Various materials, for example, materials containing iron oxides such as ferrites (including a spinel type ferrite), and an iron alloy such as alnico (Al—Ni—Co) can be adopted as the ferromagnetic materials. It is possible to appropriately suppress electromagnetic noise by adopting the ferromagnetic material. The material of the magnetic substances **210** and

210*b* is not limited to the ferromagnetic materials, and a paramagnetic material may be adopted. It is also possible to suppress electromagnetic noise in this case.

(2) The configuration of the magnetic substance structure is not limited to the configurations illustrated in FIGS. **1** and **2**, and various configurations including a magnetic substance and a conductor can be adopted. For example, a coil-shaped conductor may be embedded in a magnetic substance. Typically, a configuration, in which the conductor is connected in parallel with at least a part of the magnetic substance on the conductive path connecting the end of the magnetic substance structure on the leading end direction D**1** side to the end of the magnetic substance structure on the rear end direction D**2** side, is preferably adopted. When such a configuration is adopted, the magnetic substance is capable of suppressing electromagnetic noise. Since the conductor is capable of reducing the end-to-end resistance of the magnetic substance structure, it is possible to suppress an increase in the temperature of the magnetic substance structure. As a result, it is possible to suppress the occurrence of damage to the magnetic substance structure.

As illustrated in FIGS. **4** and **5**, the magnetic substance structure may be configured to adopt a member in which a conductive substance (conductor), a magnetic substance, and a ceramic are mixed together. The conductive substance may contain a plurality of types of conductive substances (for example, both of metal and a perovskite type oxide). The magnetic substance may contain a plurality of types of iron-containing oxides (for example, both of Fe_2O_3 and a hexagonal ferrite ($BaFe_{12}O_{19}$)). The ceramic may contain a plurality of types of components (for example, both of SiO_2 and B_2O_3). In any case, a combination of the conductive substance, an iron-containing oxide as the magnetic substance, and the ceramic is not limited to the combinations of those materials in the samples in Tables 2 and 3, and other various combinations can be adopted. In any case, the composition of the conductive substance and the composition of the iron-containing oxide can be specified by various methods. For example, the compositions may be specified by a micro X-ray diffraction method.

(3) Instead of the method by which the materials of the magnetic substance structure **200***d* are disposed and fired in the through hole **12***d* of the insulator **10***d*, other arbitrary methods can be adopted to manufacture the magnetic substance structure **200***d* illustrated in FIGS. **4** and **5**. For example, the materials of the magnetic substance structure **200***d* may be molded into a tubular shape using a molding die, and the molded body may be fired to produce a fired magnetic substance structure **200***d* having a tubular shape. The fired magnetic substance structure **200***d* may be inserted into the through hole **12***d* instead of inserting the material powders of the magnetic substance structure **200***d* when the through hole **12***d* of the insulator **10***d* is filled with the material powders of other members **60***d*, **70***d*, **75***d*, and **80***d*. It is possible to form the conductive sealing portions **60***d*, **75***d*, and **80***d*, and the resistor **70***d* by inserting the terminal metal fixture **40***d* into the through hole **12***d* through the rear opening **14** with the insulator **10***d* heated.

(4) The configuration of the magnetic substance structure is not limited to the configurations illustrated in FIGS. **1**, **2**, **4**, and **5**, and other various configurations can be adopted. For example, the configurations of the magnetic substance structure **200***d* illustrated in FIGS. **4** and **5** may be applied to the magnetic substance structures **200** and **200***b* in FIGS. **1** and **2**. For example, members with the same configuration as those of the magnetic substance structures **200***d* illustrated in FIGS. **4** and **5** may be adopted as the magnetic substances **210** and **210***b* in FIGS. **1** and **2**. The configurations of the spark plugs **100** and **100***b* illustrated in FIGS. **1** and **2** may be applied to the spark plug **100***d* illustrated in FIGS. **4** and **5**. For example, the outer circumferential surface of the magnetic substance structure **200***b* illustrated in FIG. **4** may be covered with a similar covering portion as the covering portions **290** and **290***b* in FIGS. **1** and **2**. The magnetic substance structure **200***d* may be formed in such a way that the end-to-end resistance of the magnetic substance structure **200***d* is in the aforementioned preferable range of the end-to-end resistance of the magnetic substance structures **200** and **200***b* (for example, is in a range of 0 kΩ or greater and 3 kΩ or less, or in a range of 0 kΩ or greater and 1 kΩ or less). However, the end-to-end resistance of the magnetic substance structure **200***d* may be out of the aforementioned preferable range. At least one of the resistors **70** and **70***d*, and the sealing portions **60**, **60***d*, **75**, **75***b*, **75***d*, **80**, **80***b*, and **80***d* may contain crystalline ceramic. The magnetic substance structure **200***d* may be disposed closer to the leading end direction D**1** side than the resistor **70***d*.

(5) The configuration of the spark plug is not limited to the configurations illustrated from FIGS. **1** and **2**, Table 1, FIGS. **4** and **5**, and Tables 2 and 3, and various configurations can be adopted. For example, a noble metal tip may be provided in a portion of the center electrode **20** in which the gap g is formed. A noble metal tip may be provided in a portion of the ground electrode **30** in which the gap g is formed. An alloy containing noble metal such as iridium or platinum can be adopted as the material of the noble metal tip.

In the embodiments, the leading end portion **31** of the ground electrode **30** faces the leading end surface **20***s***1** (surface facing the leading end direction D**1** side of the center electrode **20**) to form the gap g. Instead, the leading end portion of the ground electrode **30** may face the outer circumferential surface of the center electrode **20** to form a gap.

The present invention has been described based on the embodiments and the modification examples; however, the embodiments of the invention are given to help easy understanding of the present invention, and do not limit the present invention. The present invention can be modified and improved insofar as the modification and the improvements do not depart from the purport and the claims of the present invention.

INDUSTRIAL APPLICABILITY

This disclosure can be suitably used in a spark plug of an internal combustion engine or the like.

REFERENCE SIGNS LIST

5: gasket
6: first rear end-side packing
7: second rear end-side packing
8: front end-side packing
9: talc
10, **10***c*, **10***d*: insulator (ceramic insulator)
10*i*: inner circumferential surface
11: second reduced outer diameter portion
12, **12***c*, **12***d*: through hole (axial hole)
13: nose portion
14: rear opening
15: first reduced outer diameter portion
16: reduced inner diameter portion
17: leading end side trunk portion

18: rear end-side trunk portion
19: flanged portion
20: center electrode
20*s*1: leading end surface
21: electrode base member
22: core member
23: head portion
24: flanged portion
25: nose portion
30: ground electrode
31: leading end portion
35: base member
36: core
40, **40*c***, **40*d***: terminal metal fixture
41: cap installation portion
42: flanged portion
43, **43*c***, **43*d***: nose portion
50: metal shell
51: tool engagement portion
52: screw portion
53: crimped portion
54: seat portion
55: trunk portion
56: reduced inner diameter portion
58: deformed portion
59: through hole
60, **60*d***: first conductive sealing portion
70, **70*d***: resistor
75, **75*b***, **75*c***, **75*d***: second conductive sealing portion
80, **80*b***, **80*d***: third conductive sealing portion
100, **100*b***, **100*c***, **100*d***: spark plug
200, **200*b***, **200*d***: magnetic substance structure
210, **210*b***: magnetic substance
220, **220*b***: conductor
290, **290*b***: covering portion
300, **300*b***, **300*c***, **300*d***: connection portion
800: target region
810: ceramic region
812: pore
812*a*, **812*b***: protruding portion
820: conductive region
825: conductive grain region
g: gap
CL: center axis (axial line)

Having described the invention, the following is claimed:

1. A spark plug comprising:

an insulator having a through hole extending in a direction of an axial line;

a center electrode, at least a part of which is inserted into a leading end side of the through hole;

a terminal metal fixture, at least a part of which is inserted into a rear end side of the through hole; and

a connection portion connecting the center electrode and the terminal metal fixture together in the through hole,

wherein the connection portion includes:

a resistor; and

a magnetic substance structure including a magnetic substance and a conductor and being disposed on a leading end side or a rear end side of the resistor while being positioned away from the resistor,

wherein, among the resistor and the magnetic substance structure, when a member disposed on a leading end side is defined as a first member and a member disposed on a rear end side is defined as a second member, the connection portion further includes:

a first conductive sealing portion that is disposed on a leading end side of the first member and is in contact with the first member;

a second conductive sealing portion that is disposed between the first member and the second member and is in contact with the first member and the second member; and

a third conductive sealing portion that is disposed on a rear end side of the second member and is in contact with the second member,

wherein the magnetic substance structure contains:

(1) a conductive substance as the conductor;

(2) an iron-containing oxide as the magnetic substance; and

(3) a ceramic containing at least one of silicon (Si), boron (B), and phosphorous (P), and

wherein, in a cross-section of the magnetic substance structure including the axial line, when a target region is defined as a rectangular region having the axial line as a center line, a side of 1.5 mm in a direction perpendicular to the axial line, and a side of 2.0 mm in the direction of the axial line,

a region of the conductive substance includes a plurality of grain-shaped regions in the target region,

a proportion of a number of grain-shaped regions having a maximum grain size of 200 μm or greater among the plurality of grain-shaped regions is 40% or more, and

a proportion of an area of the region of the conductive substance is 35% or greater and 65% or less in the target region.

2. The spark plug according to claim **1**,

wherein an electrical resistance between a leading end and a rear end of the magnetic substance structure is less than or equal to 3 kΩ.

3. The spark plug according to claim **2**,

wherein the electrical resistance between the leading end and the rear end of the magnetic substance structure is less than or equal to 1 kΩ.

4. The spark plug according to claim **1**,

wherein the conductor includes a conductive portion penetrating through the magnetic substance in the direction of the axial line.

5. The spark plug according to claim **1**,

wherein the magnetic substance structure is disposed on the rear end side of the resistor.

6. The spark plug according to claim **1**,

wherein the connection portion further includes a covering portion that covers at least a part of an outer surface of the magnetic substance structure while being interposed between the magnetic substance structure and the insulator.

7. The spark plug according to claim **1**,

wherein the magnetic substance is made of a ferromagnetic material containing an iron oxide.

8. The spark plug according to claim **7**,

wherein the ferromagnetic material is a spinel type ferrite.

9. The spark plug according to claim **1**,

wherein the magnetic substance is a NiZn ferrite or a MnZn ferrite.

10. The spark plug according to claim **1**,

wherein the conductive substance contains a perovskite type oxide which is represented by general formula ABO_3 and an A site in the general formula is at least one of La, Nd, Pr, Yb, and Y.

11. The spark plug according to claim **1**, wherein the conductive substance contains at least one metal of Ag, Cu, Ni, Sn, Fe, and Cr.

12. The spark plug according to claim **1**, wherein, in the target region in the cross-section of the magnetic substance structure, a porosity of a remainder of the target region other than the region of the conductive substance is less than or equal to 5%.

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